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TRANSACTIONS

OF THE

AMERICAN INSTITUTE

OF

ELECTRICAL ENGINEERS.

CONTENTS.

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PUBLISHED MONTHLY (EXCEPTING JULY AND AUGUST) BY THE INSTITUTE, UNDER THE SUPERVISION OF THE EDITING COMMITTEE.

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I-T-E Remote Control Switches for Equalizer Circuits

Where equalizer leads are run from the generator to the switchboard and back through a considerable distance, not only are the series field circuits given unduly high resistance, but in addition to this the cost of the copper cables becomes excessive. While these conditions render obvious the desirability of having the equalizer switches located close to the generators, at the same time it is also evident that these switches must be under the immediate control of the switchboard attendant.

We illustrate herewith a pair of equalizer switches which we have designed and developed to meet these conditions. The right-hand switch is of 2000 amperes, the left-hand of 3000 amperes capacity. The upper terminal of each connects with the equalizer main, which takes the place of the equalizer bus otherwise required at the switchboard.

The closing and opening of the switches is effected from the switchboard by the movement of a small double throw switch.

THE CUTTER CO.

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Circuit Breaker Engineers and Manufacturers

TRANSACTIONS

OF THE

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Vol. XXI. DECEMBER, 1904. No. 10

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SECTION I.

GENERAL INSTITUTE MATTERS.

This section contains INSTITUTE matters of general interest formerly printed in the Monthly Announcement. Being of a temporary nature these items will not be printed in the bound volumes. In future the bound volumes will contain only matters that are intended for permanent record—reports of committees, technical papers, discussions on these papers, and written communications relating to them.

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NEXT MEETING, DECEMBER 23, 1904.

TRANSMISSION PROBLEMS.

The Maximum Distance to which Power can be Economically Transmitted, by RALPH D. MERSHON, Member; Consulting Electrical Engineer, New York and Montreal.

PLACE OF MEETING,
CHAPTER ROOM, CARNEGIE HALL,
154 West 57th Street, New York.

FUTURE MEETINGS.

January 27, 1905.

CENTRAL STATIONS.

February 24, 1905.

TRANSPORTATION.

APPLICATIONS FOR ELECTION.

Applications have been received by the Secretary from the following candidates for election to the INSTITUTE as Associates, and will be considered by the Board of Directors at a future meeting.

Any Member or Associate objecting to the election of any of these candidates should so inform the Secretary before January 27, 1905.

4190	Joseph M. Roman,	New York City.
4191	Francis L. O'Bryan,	So. Framingham, Ala.
4192	James C. DeLong,	Philadelphia, Pa.
4193	John R. Anderson, Jr.,	Pittsfield, Mass.
4194	Harry B. L. Gorman,	Madison, Wis.
4195	Albert E. Wood,.	Pittsfield, Mass.
4196	Herbert M. Hallsworth,	Edgewood Park, Pa.
4197	Joseph F. Lewis,	Lynn, Mass.
4198	Lonnie J. Pierce,	E. Pittsburg, Pa.
4199	James W. Bridge,.	Connellsville, Pa.
4200	James Todd,	Sewickley, Pa.
4201	John H. Hubbs,	Germantown, Phila., Pa.
4202	Wilfred Barnes, Jr.,	Pittsburg, Pa.
4203	Clarence C. Slater,	Columbus, O.
4204	William W. Lyon, Jr.,	New York City.

4205	William E. Springsteel,	New York City.
4206	Allan Coggeshall,	New York City.
4207	Charles G. Cox,	Schenectady, N. Y.
4208	John C. Barry,	Schenectady, N. Y.
4209	Frank W. Watts,	Washington, D. C.
4210	Philip J. Kearny,	Wilkinsburg, Pa.
4211	William W. Adams,	Cleveland, O.
4212	J. H. Gugler,	Minneapolis, Minn.
4213	Max A. Pooler,	Lafayette, Ind.
4214	Harold B. Vincent,	New York City.
4215	Lars R. Jorgensen,	Los Angeles, Cal.
4216	Jay H. Hall,	Cleveland, O.
4217	E. Kilburn Scott,	London, Eng.
4218	Charles J. Hillman,	Lima, Peru.
4219	David M. Donnan,	New York City.
4220	Ernest L. Brundrett,	Philadelphia, Pa.
4221	Oral M. Chinn,	Mt. Vernon, O.
4222	Joseph I. Matthias,	Winston Salem, N. C.
4223	Alexander E. Murray,	Buenos Aires, Arg. Rep.
4224	Edward A. Briscoe,	Provo, Utah.
4225	J. C. A. A. Lichtenberg,	New York City.
4226	Charles E. Yetman.	New York City.
4227	Paul Cheever,	Niagara Fall, N. Y.
4228	Josiah P. Jollyman,	Cupertino, Cal.
4229	Charles W. Fletcher,	Boston, Mass.
4230	Charles E. Phelps, Jr.,	Baltimore, Md.
4231	B. C. Bonnarjee,	New York City.
4232	Harry M. Horton,	New York City.
4233	Clement F. Scott,	Pittsburg, Pa.
4234	Eustace William Ackland,	Dunedin, N. J.
4235	Charles Hamilton Vaughen,	Lynn, Mass.
4236	Charles Anderson Sears,	Electron, Washington.
4237	Henry Elliot Waggaman,	Washington, D. C.
4238	Bradley Franklin White Bryant,	Brant Rock, Mass.
4239	John McRae,	New York City.
4240	Harry Hamilton Knox,	Seattle, Washington.
4241	Edward Woodbury,	Los Angeles, California.
4242	Alfred W. Kiddle,	New York City.
4243	Edwin Ruther Townsend,	Columbus, Ohio.
4244	Isaac Hamilton,	New York City.
4245	Marvin Shiebler,	New York City.
4246	Fred. Charles Hanker,	Williamsburg, Pa.
4247	George Cutter,	Chicago, Illinois.
4248	Edward M. Marvin,	New York City.

Total, 59.

APPLICATIONS FOR TRANSFER FROM ASSOCIATE TO THE GRADE OF MEMBER. FIRST READING.

Recommended for transfer by Board of Examiners, November 2, 1904.

SIDNEY R. SHELDON, Professor of Electrical Engineering, University of Idaho, Moscow, Idaho.

LOCAL ORGANIZATIONS—DIRECTORY.

	Branches Organized.	Chairman.	Secretary.	Branch Meets.
Branches.	**Chicago** 1893	George A. Damon.	Peter Junkersfeld.	1st Tuesday after N. Y. meeting.
	Minnesota ..... Apr. 7, '02	George D. Shepardson.	E. P. Burch.	1st Friday after N. Y. meeting.
	Pittsburg ..... Oct. 13, '02	Norman W. Storer.	S. M. Kintner.	2d Monday after N. Y. meeting.
	Denver ..... Dec. 8, '02	Henry L. Doherty.	Eugene Y. Sayer.	2d Thursday.
	Cincinnati ..... Dec. 17, '02	B. A. Behrend.	Louis E. Bogen.	
	St. Louis ..... Jan. 14, '03	W. E. Goldsborough.	Gerard Swope.	2d Wednesday.
	Schenectady ..... Jan. 26, '03	C. P. Steinmetz.	R. Neil Williams.	
	Philadelphia ..... Feb. 18, '03	H. A. Foster.	H. F. Sanville.	2d Monday.
	Boston ..... Feb. 13, '03	C. L. Edgar.	G. H. Stickney.	1st Wednesday.
	Washington, D. C. .. Apr. 9, '03	Samuel Reber.	Philander Betts.	1st Thursday.
	Toronto ..... Sept. 30, '03	T. R. Rosebrugh.	R. T. MacKeen.	2d Friday.
	Columbus ..... Dec. 20, '03	L. G. White.	M. C. Hull.	2d & 4th Mondays
	Seattle ..... Jan. 19, '04	K. G. Dunn.	W. V. Sullivan, Jr.	2d Saturday.
	Atlanta ..... Jan. 19, '04 Mar. 25, '04	A. M. Schoen.	W. R. Collier.	
	Pittsfield ..... Mar. 25, '04	F. A. C. Perrine.	D. B. Rushmore.	Alternate Fridays.
University Branches.	**Cornell University** Oct. 15, '02	Harris J. Ryan.	Geo. S. Macomber.	2d and 4th Tuesdays.
	Lehigh University .. Oct. 15, '02	Wm. S. Franklin.	William Esty.	3d Thursday
	Univ. of Wisconsin Oct. 15, '02	J. P. Mallett.	George C. Shaad.	Every Thursday.
	Univ. of Illinois ... Nov. 25, '02	W. H. Williams.	Morgan Brooks.	
	Purdue University. Jan. 26, '03	W. E. Goldsborough.	J. W. Esterline.	Alternate Wednesdays.
	Iowa State College. Apr. 15, '03	L. B. Spinney.	M. P. Cleghorn.	1st Wednesday.
	Worcester Polytechnic Institute ..	J. A. Johnson.	G. H. Gilbert	Dec. 9, 1904; Jan. 6, Feb. 10, Mar. 10, Apr. 21, May 12, 1905.
Student Meetings.	**Ohio State Univ.** .... Dec. 20, '02	W. R. Work.	F. C. Caldwell.	1st and 3d Wednesdays.
	Penn. State College Dec. 20, '02	C. L. Christman.	H. L. Frederick.	Every Wednesday
	Univ. of Missouri .. Jan. 10, '03	H. B. Shaw.	W. E. Dudley.	1st Friday.
	Armour Institute .. Feb. 26, '04	C. E. Freeman.	C. E. Freeman.	3d Monday.
	Washington Univ .. Feb. 26, '04	A. S. Langsdorf	A. S. Langsdorf.	1st Friday.
	Univ. of Michigan .. Mar. 25, '04	H. S. Carhart.	G. W. Patterson, Jr.	1st and 3d Wednesdays.
	Univ. of Arkansas. . Mar. 25, '04	W. N. Gladson	W. A. Treadway.	1st & 3d Tuesdays

LOCAL ORGANIZATIONS—MEETINGS.

	Branch.	Date of Meeting.	Subject Discussed.*	Attendance.
Branches.	Chicago			
	Minnesota	Nov. 4.	The Telautograph (I). Electrical Features at the St. Louis Fair (O).	20
	Pittsburg	Nov. 14.	Transmission of Intelligence (I). The Protection of Telephone Lines when Used in Proximity to High-Tension Circuits (O).	100
	Denver			
	Cincinnati			
	St. Louis			
	Schenectady	Oct. 26.	International Electrical Congress: (Lecture by Messrs. Steinmetz and Slichter) (O).	90
	Philadelphia			
	Boston	Nov. 17.	The Telautograph (I).	60
	Washington, D. C.	Nov. 16.	Transmission of Intelligence (I).	45
	Toronto	Oct. 28.	High-Tension Transmission (I).	12
	"	Nov. 18.	Single-phase Railway Motors (O).	22
	Columbus	Nov. 14.	The Telephone (O).	15
	Seattle			
	Atlanta			
	Pittsfield	Nov. 11.	Power-house Design (O).	34
	"	Nov. 25.	Transmission of Intelligence (I). The 2200 h.p. electric locomotive built for the N. Y. C. & H. R.R. (O).	14
University Branches.	Cornell University	Oct. class schedule.	Transmission of Intelligence (I).	85
	Lehigh University	Nov. 17.	Physics and Transmission (O).	40
	Univ. of Wisconsin			
	Univ. of Illinois			
	Purdue University	Oct. 14.	High-Tension Transmission (I).	34
	" "	Nov. 9.	The Telautograph (I).	15
	Iowa State College	Nov. 17.	The Telautograph (I). Report of the St. Louis Inspection Trip of the Senior Mechanical and Electrical Engineers (O).	33
	Worcester Polytechnic Inst	Nov. 11.	Electrical Engineering at the St. Louis Fair. (Lecture by Professor H. B. Smith) (O).	60
Student Meetings.	Ohio State Univ	Nov. 16.	Automatic Electric Elevators (O).	35
	Penn. State College	Nov. 9.	Telegraphy (O).	50
	" " "	Nov. 17.	Voltmeter Compensators (O).	30
	Univ. of Missouri	Nov. 4.	High-Tension Transmission (I).	14
	Armour Institute			
	Washington Univ	Nov. 11.	The Telautograph (I). High-Tension Transmission (I).	14
	Univ. of Michigan			
	Univ. of Arkansas			

* (I) Indicates INSTITUTE papers.
(O) Indicates Original papers.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Meeting of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, held at the Chemists' Club, New York City, Friday evening, October 28, 1904. President Lieb called the meeting to order at 8 30 o'clock.

The Secretary announced that at the meeting of the Board of Directors held during the afternoon, there were 42 Associates elected.

(See page xvi. of November, 1904 TRANSACTIONS.)

The Secretary announced further that the Chapter Room of Carnegie Hall has been engaged for the meetings of the INSTITUTE for the remainder of this season.

The Secretary announced further the death on October 26, of Mr. Max Osterberg, of New York City, a member of the INSTITUTE; and of Professor B. S. Lanphear, of the Iowa State College, Ames, Iowa.

PRESIDENT LIEB: Before taking up the papers of the evening, I take the opportunity of offering a few remarks introductory to the opening of the new season. The membership of the INSTITUTE is increasing rapidly, its work is constantly broadening in scope, and its activities spreading into new fields. Many of you are familiar with the work of the INSTITUTE only by attendance at its meetings from month to month, or through the TRANSACTIONS and communications which from time to time come into your hands. The officers and committees to whom are entrusted the administration of the INSTITUTE and the conduct of its affairs, come formally before the general membership only as their work may appear officially in the TRANSACTIONS.

The work done by your Board of Directors and the committees who have the direction of the routine work of the INSTITUTE, and the faithfulness and loyalty and constancy which they show in conducting its business, is known and can be appreciated only by such of our members as may be brought into direct contact with its manifold interests. The amount of work done by the members of the numerous committees in advancing the interests of the INSTITUTE, in upholding its prestige, and in extending its usefulness, necessitates the expenditure of much time and energy and should receive the highest

commendation; but I fear that it fails perhaps in receiving the full measure of appreciation which it deserves. Such standing committees as the Editing Committee, the Board of Examiners, Committee on Papers and Meetings, Committee on Local Organization, Library Committee, Membership Committee, and others, are called upon for a large amount of important work. The Board of Examiners particularly, to which is referred the application for admission of new members and associates, is entrusted with duties of the greatest delicacy, requiring a faithfulness and conscientiousness in their discharge which can only be appreciated by those who have served on the Board. I take pleasure at this time in paying a hearty tribute to the splendid service which your representatives on these committees render, and whose work very seldom comes before you in our formal meetings.

During the past summer the activities of the representatives of the INSTITUTE have been largely occupied in preparing a welcome and extending hospitality to the official guests of the INSTITUTE—the Institution of Electrical Engineers of Great Britain, representatives of other foreign electrical engineering societies, and visitors to the International Electrical Congress at St. Louis. We had the pleasure of having with us a delegation of over 70 members, including a number of ladies, from the Institution of Electrical Engineers, including President Robert Kaye Gray and a number of members of the Council. It afforded us a most desired opportunity to reciprocate the splendid hospitality received by our members in connection with their visit to the International Electrical Congress at Paris in 1900. We were also honored with the visit of a large delegation—over 45 in number—from the Associazione Elettrotecnica Italiana, headed by Professor Moisé Ascoli, and representative electrical engineers from France, Germany, Spain, and other foreign countries. These visitors, including a number of official delegates from foreign governments to the Congress, joined the INSTITUTE in a tour organized by it for their entertainment, visiting many of the important industrial centres of our country. The cities visited in the order named were Boston, New York, Schenectady, Montreal, Niagara Falls, Chicago, St. Louis, Pittsburg, Washington, and Philadelphia, and in each of these cities the INSTITUTE was represented by an influential Local Committee, under the chairmanship of a prominent member of the INSTITUTE, representing the most important local electrical enterprise. To these local committees was intrusted the organization and carrying out of the local entertainment, the fund for which was contributed by prominent local electrical interests. The splendid hospitality extended to the visitors in every city visited bore eloquent testimony to the effective work of the local committees. The INSTITUTE is very greatly indebted to the local chairmen and their committees who represented it in the planning and carrying out of the

local entertainments which were so greatly enjoyed and heartily appreciated by all who had the good fortune of participating in them. I will not go into further details of this tour, suffice it to say that it was a memorable event in the annals of the INSTITUTE and its reputation for the hospitality and cordiality with which it entertains its visiting friends was fully maintained.

In connection with this tour, it was arranged that each local committee should publish an electrical hand-book, which was presented to the visitors before arrival and containing a description of the interesting electrical and general industrial features of the city, with valuable statistics, historical sketches, etc. These books form an interesting library of ten small volumes, uniform in size, binding and general execution, and constituting a valuable permanent memento of the trip. The local committees published an edition of 1000 of each hand-book, of which 600 copies were kindly donated to the INSTITUTE for distribution to the visitors taking part in the circular tour, the general and local committees, Board of Directors of the INSTITUTE, Officers and Committee of Organization of the Congress, etc. It is a matter of regret that sets are not available for distribution to the entire membership, but the expense of such a general distribution would be prohibitive.

While at St. Louis, where a convention and a joint meeting with the Institution was held, the INSTITUTE was presented by the Institution of Electrical Engineers of Great Britain with a fine large painting representing Dr. William Gilbert appearing before Queen Elizabeth. This splendid painting will no doubt occupy a conspicuous place in our new quarters in the Union Engineering Building.

This leads me to say a few words in connection with this important work, the progress of which has been reported to you from time to time. The work of carrying into effect the munificent gift of Mr. Andrew Carnegie to the National Engineering Societies and the Engineers' Club, so far as the INSTITUTE is concerned has been in the hands of one of your most efficient committees, represented by Messrs. Scott, Arnold, and Wheeler, and your committee has taken a prominent part in formulating the plan on which this important undertaking should go forward. As you know, at an early stage in the development of this project the American Society of Civil Engineers decided that it would not coöperate in this matter. It was feared—and it was indeed a trying moment—that their withdrawal might wreck the whole enterprise. But when the condition of affairs was brought to the attention of Mr. Carnegie, and it was explained to him that there were many other technical societies, some national and some local in character, which would desire to maintain headquarters in the Union Engineering Building, and which in number of members represented would make up for this defection, he confirmed the gift and in fact most generously increased it, so that there is now available for the erection

of the building for the United Engineering Societies and the Engineers' Club, a donation amounting in the total to $1 500 000. Your committee, together with the committees of the other engineering societies and the Engineers' Club, are now actively engaged in having plans drawn up and the formulating of contracts and agreements for carrying out the purpose of this gift.

I will close these remarks by calling upon Mr. C. F. Scott, one of the representatives of the INSTITUTE on its general committee, to give you further details as to the progress of the work.

I must crave your indulgence this evening as I have been invited as President of the INSTITUTE to take part in the dinner of the Department of Electrical Engineering at Columbia University, to celebrate the 15th anniversary of the organization of the Department. I hope you will therefore excuse me now in order that I may discharge my duties elsewhere, and I will ask Vice-president Rice please to take the chair.

C. F. SCOTT: The last time I appeared before the INSTITUTE upon this subject was, I believe, last May. I stated at that time that the architects were working upon the plans. A little later, in the latter part of June, plans were received from 26 different architects. These were duly numbered, and corresponding numbers with the names were put in sealed envelopes. There were 26 sets of plans for the Engineering Building, each consisting of a dozen, more or less, drawings. There were likewise 26 sets of plans for the Engineers' Club. The representatives of the Engineering Building from the various societies considered one set of plans, and the representative of the Engineers' Club considered the other set. A careful study was made of them, meeting day after day, sometimes in committee and sometimes individually. The plans were considered in detail, they were sorted out as to acceptable facades, general assemlby rooms, smaller meeting rooms, and the library. It was a very interesting study. Several of us formed them in the rank of merit as they appealed to us individually, and then made comparisons. We found in general that seven of the plans fell within the first ten that most of us had chosen.

Professor Ware, our architectural adviser, independently selected six of the plans which appealed to him as superior. We found that five of the six were among the seven which the committee had chosen as most nearly meeting its views. For one reason and another, none of the sets were wholly satisfactory; but there was one set which, while it did not meet the views of the committee as it stood, could, without sacrificing the general arrangements, be made to meet the views of the committee, as Professor Ware understood them. Professor Ware suggested the changes which could be made, and the committee unanimously chose that set of plans. When the envelopes were opened it was found that Mr. Robert D. Hale was the architect. Mr. Hale is from Boston, but has had an office in this city for some two years past. He is the son of the well-known Dr.

Edward Everett Hale, and, by the way, when he came here he had a letter of introduction to a few gentlemen from his father. He told me that he expected to find these letters addressed to some of the noted divines of this city, but they were to business men, and one of these men was Mr. Carnegie. He presented this letter to Mr. Carnegie and had a talk with him, and Mr. Carnegie gave him his best wishes for success in the city.

The choice of the plans was made in July. Various circular tours, summer vacations, and that sort of thing interfered with consecutive work during the latter part of the summer, although the committee took up at once with the architect some of the changes and modifications the committee would like, and he went to work on them. The architect is meeting with the committee from time to time, and the plans are progressing. The sub-committee on building has had several meetings with him this week and everything is going nicely. The committee hopes to be able to have the plans in a fairly matured shape so that they may be taken up with the Board of Directors for final suggestions and issued to the general membership before very long. A general outline of the building may be given at this time.

It is to be on 39th Street, midway between Fifth and Sixth Avenues, facing south. The entrance floor will have a large central corridor, with offices for administration and the like; in general it is to be a large assembling place for those who enter the building. Audiences upon being dismissed will not be crowded in a small corridor but will have a large circulating place for leaving the building. There will be a carriage drive around the whole building, covered on one side. The building itself will be practically free and open on all sides. At the east side Mr. Carnegie has generously purchased a lot and put a building restriction on it, so that there will be no house on the lot higher than four stories. That will give light and air to the east for the upper floors perpetually. On the west there is planned a ten foot vacant space on our own property, which will never be built upon, and on the rear there is a little space for the driveway, so that with the exception of a small portion of the east side we will have air and light on all sides of the building. On the second floor there will be a large auditorium seating somewhere from 1200 to 1500 persons. The plan is to have ample corridors around the meeting room, for convenience of visitors and for those that want to talk. Above will be smaller lecture halls, seating several hundred. One of these will be in amphitheatre style, so that any experiments or demonstrations can be readily seen. There will be some smaller halls also, for smaller meetings. The upper floors will be set aside for the various societies, for the use of secretaries, board rooms, and the like. And if it is pleasing to the societies, there will be facilities for one or two rooms fitted up on club style, which will make a comfortable place to sit and talk, with a writing and

reading room. There will be ample room for the other societies which desire quarters in the building. There are a number of branches of engineering societies in existence now which will undoubtedly desire quarters in the building, such as railway clubs, chemical societies, societies of gas engineers, societies of municipal engineers, and the like. There are a dozen or more that were communicated with last year and they were found to be acceptable to the idea of their coming in and sharing the building. At the top there will be a large library, with overhead light over the reading room on the upper floor, with stackroom just below. At the suggestion of the general building committee, the several societies have appointed a general committee on library, with the idea of bringing the libraries of the various societies together and making it the nucleus for a great engineering library. That work is under way and something notable can be hoped for in that direction.

One other line of work which received a great deal of attention is that of organization. We had considered the question of the way in which the three societies shall be united to purchase the lots and hold title to the lots and the building. The plan determined upon is the formation of a separate organization under the title of the United Engineering Society, which has been authorized by a special law passed by the New York Legislature at the last session. This United Engineering Society is to be composed of three representatives from each of the so-called founder societies. By-laws for the government of this society have been drafted and these by-laws have been submitted to the several societies and have in general received their endorsement. There are a few particulars which are being looked after, but there is a substantial agreement on the matter, and the consummation of the plan may be looked for in the near future; so that the building in its plans and the building in its organization is progressing nicely. The work is a large one and involves more in detail and in time than I had hoped would be the case, but many interests have to be considered and the undertaking is large; so that while I wish we were laying bricks now, I feel on the whole that the time taken is time well spent. The lots have been cleared of the buildings, and if you chance to be in that part of the city you can see the space which will be occupied in another way in the near future.

ASSOCIATES ELECTED NOVEMBER 25, 1904.

ADAMS, SPENCER, Electrical Enginneer, Sociedad Al. Electrico de Piedra Lisa, Lima, Peru.	A. W. McLimont. R. W. Lohmann. J. K. Robinson.
ALLEN, ALBERT MARK, Electrical and Mechanical Engineer, with George Hill, 100 Broadway, New York City.	George Hill. E. E. Ellinger. C. F. Tischner.
ALEXANDER, GEORGE RANDALL, Constructing Foreman and Electrician, Central California Electric Co., 1003 K St., Sacramento, Cal.	R. W. VanNorden. C. W. Hutton. Lawrence Ettrup.
BEAUJON, ANTON RUDULOF, Secretary and General Manager, East Coast Electric Light, Power and Ice Co., West Palm Beach, Fla.	F. F. Bahnson. Wm. Maver, Jr. R. W. Pope.
BERRY, MAXWELL RUFUS, Assist. Supt. of Construction, Pittsburg, McK. and Connellsville Railway Co., Connellsville, Pa.	W. E. Moore. J. L. Merrill. Thomas Elliott.
CARTER, HENRY HARCOURT, Student, Electrical Engineer Institute; res. Broad St., Barbados, B. W. I.	A. W. Gray. Jefferson Wetzler. R. W. Pope.
CLARKE, HERBERT ALMYR, Consulting Engineer, 829 Perry Building, Philadelphia.	C. A. Bragg. F. P. Spiese. W. L. Conwell.
COCHRANE, HARRY HAMILTON, Instructor in Physics, Cornell University, Ithaca, N. Y.	H. H Norris. W. L. Robb. Frederick Bedell.
COWLING, JOHN T., Electrical Engineer, Westchester Lighting Co., Mt. Vernon, N. Y.	Paul Spencer. J. E. Hodgson. Steuart Wilder.
DALY, WILFRID AUGUSTIN, Engineering Apprentice, Westinghouse Electric and Mfg. Co., Pittsburg; res. 739 South Ave., Wilkinsburg, Pa.	L. H. Haight. Isaiah Jarcho. D. R. Bacon.
DE GRESS, FRANCIS BARRETT, Crocker-Wheeler Co., 39 Cortlandt St., New York City.	G. S. Dunn. F. V. Henshaw. A. J. Thompson.
DENNEEN, FRANCIS S., Testing Department, Brooklyn Heights Railroad; res. 421 37th St., Brooklyn, N. Y.	C. P. Matthews. J. W. Esterline. W. E. Goldsborough.
DUNSTAN, ARTHUR ST. CHARLES, Professor Electrical Engineering, Alabama Polytechnic Institute, Auburn, Ala.	J. C. Kelsey. W. S. Franklin. H. Y. Hall.
EMERSON, LUTHER LEE, Manager, Clark and McMullen Farmers' Bank Building, Pittsburg, Pa.	Horace Dowie. C. M. Clark. S. H. Crampton.
ENSTRÖM, ALEX FREDRIK, Professor Royal Technical Academy, 99 Regeringsgatan, Stockholm, Sweden.	J. L. Edstrom. Ernst Danielson. A. Lindstrom.
FEILDEN, THEODORE JOHN VALENTINE, Editor-in-chief *The Electrical Magazine*, 4 Southampton Row, Holborn, London W. C., England.	Wm. Maver, Jr. R. W. Pope. F. L. Hutchinson
FLOWERS, ALAN ESTIS, Instructor, University of Missouri, 704 Maryland Place, Columbia, Mo.	H. J. Ryan. H. H. Norris. H. B. Shaw.
FREUND, SIEGFRIED GEORGE, Electrical Department, Interborough Rapid Transit Co. 2439 Park Row, Building, New York City.	H. N. Latey. F. R. Slater. A. F. Ruckgaber.

GAIENNIE, LOUIS RENÉ, Superintendent, Kinloch Telephone Co.; res. 5440 Maple Ave., St. Louis, Mo.	H. L. Reber. James Harrison. Frank Gaiennie.
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GOETTLING, GERHARD MAX WILLY, Electrical Engineer, Edison Electric Illuminating Co., 516 Atlantic Ave., Boston.	J. W. Cowles. C. L. Edgar. A. H. W. Joyner.
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HARRIS, WILLIAM WOODSON, Draftsman, Union Electric Light and Power Co.; res. 3973 W. Belle Place, St. Louis, Mo.	H. B. Shaw. J. H. Siegfried. H. C. Don Carlos.
HESKETH, THOMAS, Managing Engineer, Folkstone Electricity Supply Co., Ltd.; res. Belvedere Cherelou Road, Folkestone, England.	Calvert Townley. B. J. Arnold. C. F. Scott.
HILL, LUCIEN, Assistant to General Manager, West Penn Railway and Lighting Co. Syndicate, Connellsville, Pa.	W. E. Moore. Thomas Elliott. J. L. Merrill.
HUSSEY, RALPH GOODRICH, Master Electrician, Artillery Corps, U. S. Army, Fort Adams, Newport, R. I.	C. F. Parker. William Garnett. F. W. Ralston.
JONES, THEODORE INSLEE, Electrician, N. Y. and N. J. Telephone Co., 160 Market St., Newark, N. J.	E. W. Dennison. Dudley Farrand. Calvin W. Rice.
KOHLER, L. FRANK, Student, Columbia University; res. 108 Morningside Ave., New York City.	G. F. Sever. F. B. Crocker. Morton Arendt.
LAMBERT, THOMAS B., Supt. Wiring and Maintenance, Louisiana Purchase Exposition, care City Fire Alarm Office, Chicago, Ill.	H. J. Ryan. H. T. Gibbs. W. K. Dunlap.
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MEYER, HANS JULIUS, Supt. Shreveport Gas Electric Light & Power Co., 625 Market St., Shreveport, La.	L. W. Bogen. L. L. Tatum. G. B. Foster.
MOORE, WALLACE D., "U.S.S. Petrel," San Francisco, Cal.; res., 623 N. Jefferson St., Lima, Ohio.	F. W. Roller. Wm. Maver, Jr. C. P. Poole.
MORRIS, DAVID KING, Lecturer, The University, Birmingham, Eng.	H. J. Ryan. C. C. Hawkins. R. W. Pope.
MORSE, LEOPARD GEORGE ESMOND, 14 Airlie Gardens, W., London, Eng.	B. J. Arnold. J. W Lieb, Jr. R. W. Pope.
MOSES, RUFUS PAGE, Chief Electrician, Mt. Copper Co., Ltd., Taylor, Cal.	A. J. Bowie, Jr. W. W. Hanscom. C. W. Remschel.
NEWBERRY, JORGE, General Director, Electrical Works and Public Lighting, 2368 Moldes, Buenos Aires, A. R.	F. B. H. Paine. Calvert Townley. R. W. Pope.

OWEN, LLEWELYN, Assistant Supt., Peoria Gas and Electric Co., 104 Flora Ave., Peoria, Ill.	R. S. Wallace. D. C. Jackson. C. F. Burgess.
PARTRIDGE, WARREN, Supt. United Electric Co. of N. J., Lakeside Ave., Orange, N. J.	Dudley Farrand. C. A. Adams. A. E. Truesdell.
QUIGLEY, ARTHUR JOSEPH, Assistant to Electrical Engineer, J. G. White & Co., 43 Exchange Place, New York City.	H. A. Lardner. F. P. Woy. C. D. Gray.
RENSTRÖM, JONAS ALFRED, Superintendent, Reyla Power Plant, Pachuca, Mexico.	P. O. Renstrom. M. T. Thompson. R. W. Pope.
REYNOLDS, WILLIAM HENRY, General Electric Co.; res. 288 Lenox Ave., New York City.	W. S. Franklin. R. J. Houk. H. J. Putt.
ROBERTSON, CHARLES EMERY, Assistant Sales Manager, Robertson Electric Co.; res. 158 Park St., Buffalo, N. Y.	H. B. Shaw. E. E. Schmid. R. W. Pope.
RUSSELL, CHARLES J., District Manager, Philadelphia Electric Co.; res. 3422 Disston St., Tacony, Philadelphia, Pa.	W. C. L. Eglin. G. R. Green. John Meyer.
SANFORD, WARREN BIXBY, Designing Engineer, United Telpherage Co., 20 Broad St.; res. 108 West 13th St., New York City.	H. J. Ryan. R. W. Pope. C. M. Clark.
SERGEANT, ELLIOT MATTHEWS, Chief Engineer, General Storage Battery Co., Boonton, N. J.	Joseph Bijur. W. I. Slichter. G. F. Sever.
SKINNER, WILLIAM ELBERT, Manager, Canadian Westinghouse Co., Ltd., Winnipeg, Manitoba.	C. E. Skinner. C. F. Scott. R. W. Pope.
SMITH, HARTLEY LE HURAY, Mechanical Engineer, Brooklyn Rapid Transit Co., Central Power Station, 3d Ave. and 1st St., Brooklyn, N. Y.	A. J. Rowland. R. C. Taylor. H. A. Currie.
SNYDER, HARRY RAY, Superintendent, Main Switchboard, Louisiana Purchase Exposition Co.; res. 3412 Morgan St., St. Louis, Mo.	Hoge Gilliam. H. T. Gibbs. W. K. Dunlap.
STONE, EDWARD WADSWORTH, Manager, Asheville Telephone and Telegraph Co., Asheville, N. C.	C. E. Waddell. J. D. Foy. R. W. Pope.
STRICKLAND, TOM PERCIVAL, Chief Assistant Electrical Engineer, N. S. W. Government Railways and Tramways, 51 Philip St., Sydney, N. S. W.	M. A. Oudin. A. L. Rohrer. R. B. Owens.
WALBORN, IRA GUY, Assistant, Engineering Department, Telluride Power Co., Provo, Utah.	H. B. Shaw. C. S. Ruffner. E. V. Berg.
WEBB, ARTHUR CLEMENT FREDERICK, Consulting Electrical Engineer, 82 Pitt St., Sydney, N.S.W.	B. J. Arnold. R. W. Pope. H. L. Webb.
WOLFE, ERNEST A., Electrical Engineer, Westinghouse Electric and Mfg. Co., Pittsburg, Pa.	A. F. Chamberlain C. A. Bragg. L. D. Bliss.

Total, 53.

TRANSFERRED FROM ASSOCIATE TO THE GRADE OF MEMBER, NOV. 25, 1904.

Recommended for transfer by Board of Examiners, Oct. 5 and 12, 1904.

HARRY PARKER GIBBS, Chief Engineer, Government of Mysore, Province Bangalore, India.

DOUGLASS BURNETT, General Manager, United Electric Light and Power Co., Baltimore, Md.

ARTHUR CLARKE EASTWOOD, Engineer, The Electric Controller and Supply Co., Cleveland, O.

WILLIAM AMZI DICK, Designing Electrical Engineer, Westinghouse Electric and Mfg. Co., Pittsburg, Pa.

EDWARD JEROME COOK, Chief Engineer, Cleveland Electric Railway Co., Cleveland, O.

STUDENTS OF THE INSTITUTE.

Attention is called to the extended notice regarding Students of the INSTITUTE, printed in the November, 1904, issue of the TRANSACTIONS. That notice contained a numerical list of the applications for Student enrolment received from several educational institutions.

At a recent meeting of the Board of Directors the Secretary was authorized to print the names of the Students of the INSTITUTE in conjunction with all future issues of the Directory of Membership. Attention is called to this decision, as the next Directory of Membership will be issued as of date January 1, 1905, and in this Directory will be printed the names of all Students enrolled up to January 1, 1905.

MEMOIRS OF DECEASED MEMBERS.

B. S. Lanphear.

Professor B. S. Lanphear of the Iowa State College, Ames, Iowa, died at the home of his parents in Carthage, N. Y., October 14, 1904, aged 33 years. In September he was stricken with nervous prostration, which obliged him to give up his college work. Upon the advice of his physician he went to his home; from that time on his vitality gradually failed.

Mr. Lanphear entered Cornell University in 1890, and was graduated with the degree of M.E. in 1894. In his senior year he was elected to the honorary scientific society, Sigma Xi. He received the Master's Degree in Mechanical Engineering from Cornell University in 1895. Upon leaving Cornell he was appointed instructor in physics and electrical engineering at the University of Maine. He was recalled to Cornell in 1897, and served a year as instructor in electrical engineering. The following year he accepted a position as expert engineer with the International Paper Company, resigning it later to accept a call to the Iowa State College. He married Miss Emma Park on September 16, 1899. Mrs. Lanphear and one son survive him.

Mr. Lanphear was elected an Associate of the American Institute of Electrical Engineers on January 16, 1895. During the last two years he was prominent in developing the Iowa State College Branch of the Institute. He was one of the organizers of that Branch; he infused it with a spirit that makes it one of the most active and useful Branches of the Institute; he was its Secretary from the time it was organized until his death, and through his efforts no less than 77 of his pupils were enrolled as students by the Institute between 1902 and 1904. During the last year he devoted much time in preparing the manuscript of a book which was uncompleted at the time of his death

He was a member of the Iowa Engineering Society, the American Association for the Promotion of Engineering Education, the American Association for the Advancement of Science, and the International Electrical Congress of 1904.

Bertrand B. Abry.

Bertrand Buhre Abry was born at Dubuque Iowa, October

6, 1876, and died at Pittsburg, Pa., October 31, 1904. The immediate cause of death was typhoid fever.

Mr. Abry was educated in the public schools of Cheyenne, Wyoming, and at the University of Nebraska and the University of Illinois; he was graduated at the University of Illinois with the class of 1900.

He joined the staff of apprentices at the Westinghouse Electric and Mfg. Co.'s shops at East Pittsburg in 1900. He advanced rapidly through the shops and the testing room, and later was transferred to the railway engineering department.

Mr. Abry was the author of an excellent series of articles on "Shop Testing of Motors and Generators for Commercial Service," printed during the last year in the electrical press. He was a young man of considerable ability and marked energy, and gave promise of a very useful career. He was elected an Associate of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, January 23, 1903. At the time of his death he was president of the Electric Club of Pittsburg.

MAX OSTERBERG.

Max Osterberg was born on June 12, 1869, at Frankfort-on-the-Main, Germany, and died at Brighton Heights, Staten Island, October 26, 1904. He received his primary education in the Realschule of Frankfort. He came to America when sixteen years of age, and soon after his arrival found employment as an office boy in a large manufacturing house, where he remained until his twenty-second year. While in this employment he not only advanced to the position of bookkeeper and general manager, but also qualified himself for entrance to Columbia University, New York.

After an attendance of only two years at Columbia he was graduated with high honor, receiving the degree of E.E. From 1894 to 1896, Mr. Osterberg made a special study of Hertzian waves. He also wrote a book on thermodynamics, which became a textbook in many leading colleges in this country, including Columbia. He was awarded an honorary fellowship, and in 1896 received from Columbia the degree of A.M. After the Chicago World's Fair in 1893, Mr. Osterberg was editor of the Proceedings of the International Electrical Congress. He was editor of *Electrical Power* from 1894 until 1896, and was associated at that time with Mr. T. A. Edison on his X-ray investigations.

In the fall of 1896 Mr. Osterberg started in business for himself as consulting electrical and mechanical engineer. He acted as consulting engineer for the Cunard Steamship Company of New York; he engineered the electrical construction work of the first electrical show at New York; he drew up specifications for electrical installations in many leading churches, office buildings, factories, clubs, etc., and his services were in considerable demand for trolley testing and inspecting, and other accurate scientific and engineering tests. Mr. Osterberg gave much attention to lecturing on electricity and kindred subjects, having a record of more than 900 lectures delivered before scientific societies and his classes at the Y. M. C. A. He was a member and former vice-president of the New York Electrical Society, a Member of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, the American Mathematical Society, the American Electrochemical Society, and an honorary member of the National Society of Electrotherapeutics. Mr. Osterberg was also a member of several charitable and social organizations and director in a number of industrial companies.

SECTION II.

PAPERS AND DISCUSSIONS.

This section contains INSTITUTE matters of a permanent nature; these matters will be eventually reproduced in the bound volume compiled at the end of the calendar year.

A paper presented at the 191st Meeting of the American Institute of Electrical Engineers, New York, November 25, 1904.
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PROBLEMS OF HEAVY ELECTRIC TRACTION.

BY O. S. LYFORD, JR., AND W. N. SMITH.

A study of the general subject of electric traction for the suburban lines of present steam roads discloses some interesting features which do not necessarily arise as important factors in the selection of equipment for rapid transit lines in cities or the usual interurban lines. Furthermore, the many variables that enter into the problem lead to a serious question as to the necessity of the elaborate methods of determining train and motor characteristics which have been put forth in the recent literature on heavy electric traction. The advantage of simpler and shorter methods becomes very apparent.

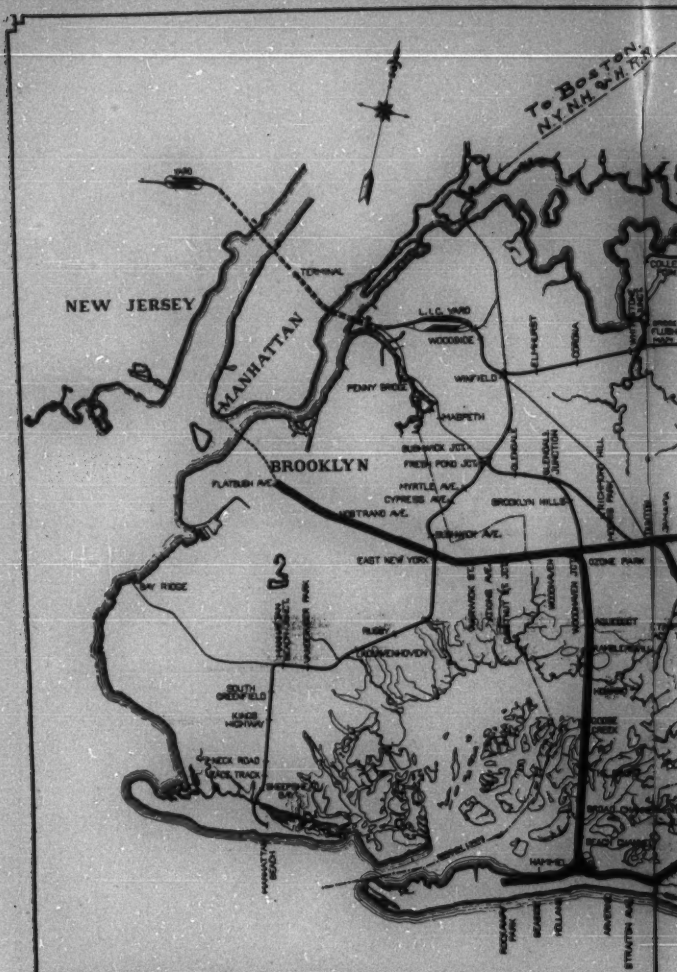
Work now in progress for the Long Island Railroad Company may be taken as typical of projects of this character. It is the purpose of this paper to place before the INSTITUTE some of the questions brought out in the engineering of this work and to describe more particularly some of the simple things that were done to facilitate decision regarding motor equipments for cars.

The Long Island Railroad system has at present two passenger terminals in the City of New York, one at Atlantic Avenue and Flatbush Avenue in the Borough of Brooklyn and one at the Thirty-fourth Street Ferry in Long Island City, Borough of Queens. When the tunnels of the Pennsylvania, New York, and Long Island Railroad Company are completed there will be a third terminal for the Long Island Railroad passenger traffic in the Borough of Manhattan. From the present terminals there branches out an extensive system of through and suburban lines, over which is maintained a train service, both express and local, reaching all parts of the Island. In addition

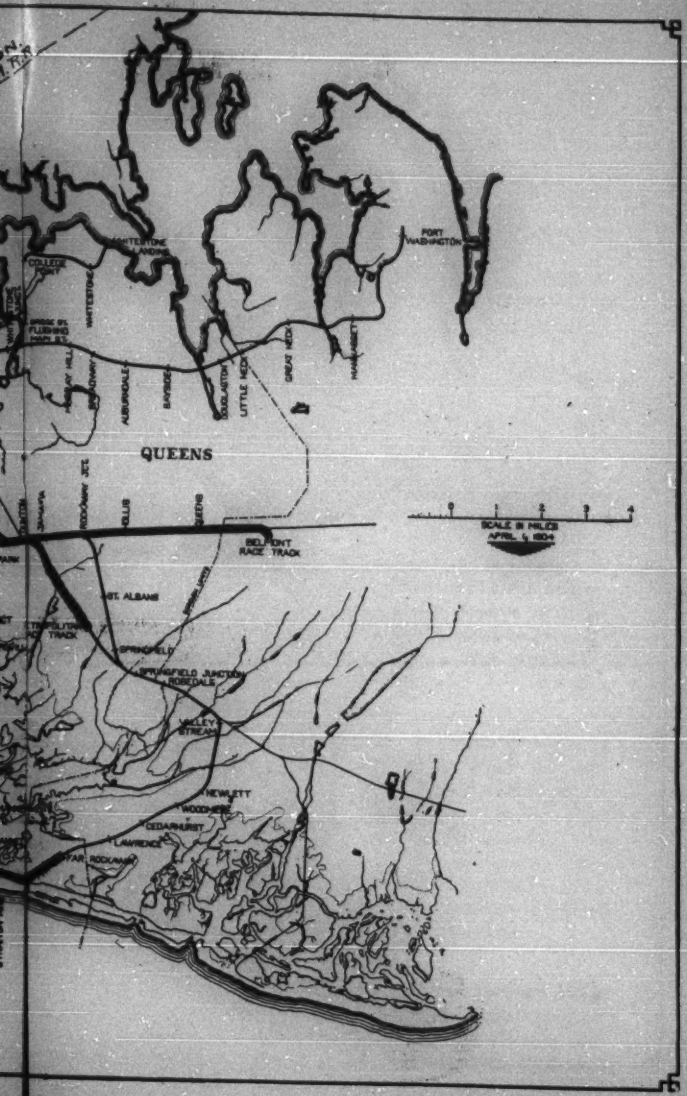
to the suburban serivce into these terminals there is an interchange of traffic with the Brooklyn Rapid Transit Company at two points, and a connection is to be established between the subway system of the Long Island Railroad in Atlantic Avenue and the extension of the Rapid Transit Subway now being constructed between Brooklyn and the south end of Manhattan. The accompanying map shows the location of the western lines of the Long Island Railroad and the new connections which are to be made.

Extensive plans for the electrification of the suburban service of this road have been under consideration for some years. These plans provide for the immediate adoption of electric traction on the lines emanating from Flatbush Avenue and for a progressive extension of electric traction over all of the strictly suburban routes, as rapidly as the conditions shall justify. On some of these routes the traffic is of a purely suburban nature, providing facilities for out-of-town residents to reach Manhattan and Brooklyn. On other sections the important traffic is an excursion movement to and from New York's great playgrounds at the beaches. For the convenience of the suburban residents, a frequent service in comparatively short trains is to be provided, but for the excursion service comparatively long trains are necessary. As a result, the number of cars per train in this system will vary from one to eight or possibly ten. The initial service, limited to a maximum of six cars per train, results in 52 types of runs varying in number of cars per train and distance between stops. On some sections the lines are fairly free from grades and curves, but on others the grades and curves are heavier than would be supposed from a general knowledge of the contour of Long Island. These few statements will indicate in a general way the complex nature of the problem involved in the selection of a suitable electrical system for such a service and in the determination of types and sizes of apparatus to be used. In the working out of large enterprises important details are frequently settled by quite simple processes of reasoning. Even in a complex problem like the one under consideration, some main points may be decided in this way.

(a) The number of cars per train varies from one to six, as stated. Eight- or ten-car trains may be desirable at times. Such variations in train length cannot be provided for economically with electrical locomotives. Motor-cars must, therefore, be used, and for all except trains of one or two cars, more than



MAP OF THE PENNSYLVANIA TERMINAL RAILROAD AND WESTERN LINES OF THE LONG ISLAND RAILROAD.—Portion to be first converted to electricity shown by heavy lines. Connection of Atlantic Avenue line with Interborough Railway System also shown.


QUEENS
PORT WASHINGTON
COLLEGE POINT
WHITESTONE LANDING
WHITESTONE
BRIDGE PL. FLUSHING
BAYSIDE
ASTORIA
LITTLE NECK
GREAT NECK
HAMILTON BEACH
JAMAICA
JAMAICA JCT.
QUEENS BLVD.
BELMONT RACE TRACK
SCALE IN MILES
APRIL 1, 1924
ST. ALBANS
SPRINGFIELD
SPRINGFIELD JUNCTION
ROSEDALE
VALLEY STREAM
NEWLETT
WOODMERE
CEDARHURST
LAWRENCE
FAR ROCKAWAY

one motor car per train is necessary. The multiple-unit system of motor-car operation is, therefore, best suited to this service.

(b) The greatest flexibility for make-up of trains is obtained by making all cars motor-cars.

(c) On the other hand the first cost of equipment and the cost of maintenance and inspection is least if the motor selected is of the largest size practicable, and the number of equipments required is thus made a minimum.

(d) For a miscellaneous service of the character contemplated all trains, both local and express, should preferably be provided with equipment having the same speed characteristics, so that all motor cars are available for all classes of service. (Trains may operate as express in one direction and as local in the other.)

(e) For express runs of this suburban service, averaging not over five miles between stops, a moderately high speed, say 50 to 55 miles per hour, is found by experience in steam practice to be most suitable. For these runs, therefore, it is essential that the electric trains shall be able to approximate these speeds.

(f) Future development of the service, such as increase in number of stops and decrease in running time, will mean heavier work for the motors. Therefore, reasonable reserve must be provided in the equipment, and consideration must be given to equipment which will make possible a convenient increase in number of motors per train.

Size of Motors:

The largest motor in general use for motor-car trains is of 200 h.p. nominal rating, two of these being about the limit of motor capacity that can be placed on a truck with 33- or 36-inch wheels and a reasonably short wheel-base. On the basis of condition (c), this should be the motor adopted, provided the train combinations can be effected satisfactorily with motors of this size. Condition (f) is also complied with by selecting the largest motor practicable, as the number of motors per train in the initial service will then be a minimum.

Gear Ratio:

To meet condition (e), a gear ratio must be selected which permits the operation of trains at high speeds without damage to the equipment. On the other hand, the best starting conditions and least heating effect are obtained with high gear

ratio. The gear ratio should, therefore, be as high as practicable and still permit of the maximum train speeds necessary for the express schedules. Provision must also be made for extra speeds which may occur on down grades. From observation of the existing service it was concluded that it is safe to assume 60 miles per hour as a maximum.

TRAIN WEIGHTS:

The motor cars of the service are to be new steel cars similar to those adopted for the Rapid Transit Subway. For the determination of motor characteristics, trailer cars were assumed to have the same size and weight of bodies. The weights assumed were as follows:

	Motor Car.	Trailer.
Seated Load	81 000 lb.	60 400 lb.
Standing Load	88 000 lb.	66 000 lb.

These assumed weights are in practical agreement with the actual weights of the subway equipment

The 200-h.p. motor was found to be the proper size for the service of the subway; but the schedule conditions are so different that this in itself does not signify that the same motors are suitable for the Long Island Railroad conditions where the distance between stops for most of the local runs is greater than that of the express runs of the subway, and the express runs are longer in proportion. More or less of the usual calculating must, therefore, be done to reach a decision as to whether the characteristics of the standard motor of this size are suitable for this service or whether a smaller size could be used to advantage.

In Volume 19 of the TRANSACTIONS of the A. I. E. E. and in the technical press of the last two or three years, there are a number of interesting papers giving theoretical and practical information regarding electric motors for railway service. Of these papers that of Messrs. Arnold and Potter on Acceleration Tests gives some very interesting results of actual records of speed-time tests of steam and electric trains of different weights, illustrated by diagrams which admit of close comparison between theoretical and practical results. The scholarly and somewhat bewildering papers by Mr. Mailloux and by Dr. Hutchinson are of interest as representing the academic side of some of the problems involved; and Mr. Gotshall contributes some very interesting illustrations of theoretical speed-time curves derived for a specific case. The subjects of train resis-

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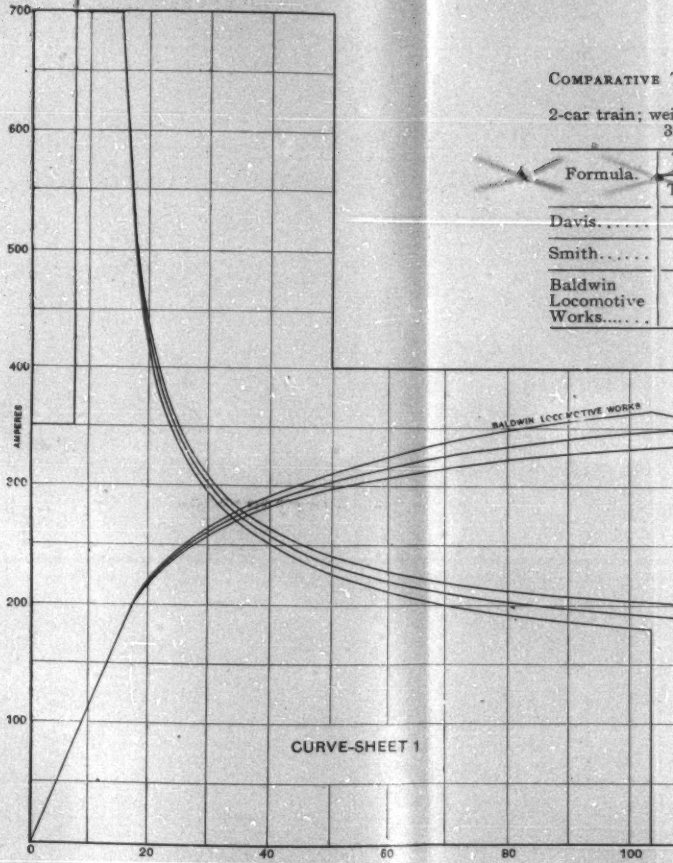


COMPARATIVE

2-car train; wei
3

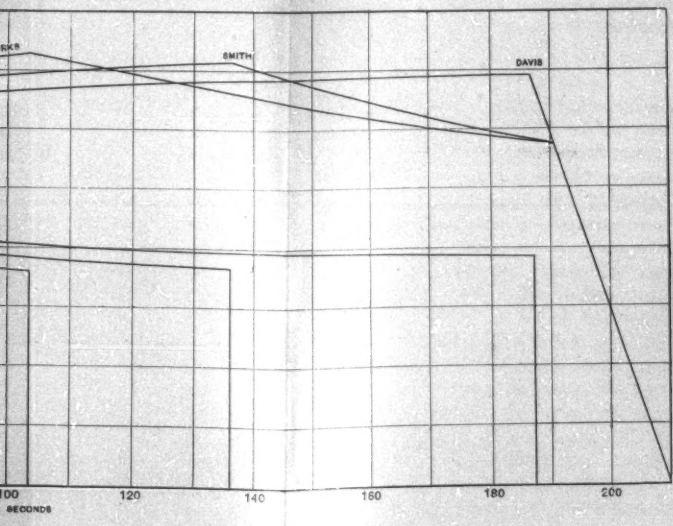
Formula.	
Davis.....	
Smith.....	
Baldwin Locomotive Works.....	

Curve Sheet 1.

...ative Train Performances Computed with Different Resistance Formulas.

...in; weight 70.6 tons; 2 Westinghouse No. 86 motors; 19:63 gear; 36-in. wheel; run 1.67 miles, level; 540 volts.

...la.	Time Seconds.		Per cent. Time Power on	Speed miles per hr.	kw–hr.	Watt-hrs per Ton Mile.
	Total	Power on				
...	210	187	89	28.6	7.51	63.6
...	210	136	65	28.6	5.76	48.8
ive ...	210	103	49	28.6	4.66	39.5



tance, acceleration rates, and rating of motors have been reported on at length and each investigator has viewed them from a different standpoint. The effect of the inertia of rotating parts of a train, previously neglected, has also been given its full share of importance. With all this information at hand, however, there are still some very pertinent questions which arise in the mind of an engineer approaching the solution of such a problem:

Who is nearest right?

How much of this tedious calculating is necessary?

Whether used to overcome mechanical friction, head resistance, gravity, or inertia, how much power must be delivered to the motor cars to move a train from one terminus to the other?

How close will practice work out to theory?

What allowance must be made for local limitations on the possible speed of train equipments?

Some of the things that were done to obtain satisfactory answers to these questions may be of interest to the members of the INSTITUTE.

I. PLOTTED AND TEST RUNS COMPARED:

The power required to overcome inertia and gravity may be calculated with exactness. Train resistance, however, made up of head resistance, mechanical friction, and skin friction, may be estimated only by empirical formulas, based on practical tests. Such formulas have been derived and published by various engineers. Owing to differences in character of equipment and road-bed, nature of the train service, design of car bodies and trucks, methods of test, etc., there are material differences in the conclusions reached. For ordinary electric car service on urban and suburban lines, where the number of stops is frequent and the maximum speed is low, the train resistance is relatively unimportant as compared with the effect of inertia and grades, but as the speed increases the train resistance becomes a more important matter. The lack of agreement of these formulas when applied to the conditions of the L. I. R. R. are illustrated in Fig. 1 of the Davis and the Baldwin Locomotive Works' formulas are extremes; they therefore afford a sufficient illustration of the divergence of authorities on this subject. These formulas are expressed as follows:

$$\text{Baldwin Locomotive Works, } R = 3 + \frac{V}{6}$$

$$\text{W. J. Davis,}\quad R = 4+0.13\,V+\frac{.004\,A\,V^2}{T}\,[1+0.1\,(n-1)]$$

R = Train resistance in lb. per ton of 2000 lb.
V = Velocity in miles per hour.
A = Cross sectional area of car in sq. ft.
T = Weight of train in tons of 2000 lb.
n = Number of cars per train.

The formula marked "Smith" is one suggested by one of the authors and has been found to give results close to actual practice as will be explained in the following paragraphs. This formula has the following expression:

$$R = 3+0.167\,V+0.0025\,\frac{A}{T}\,V^2.$$

The speed-time curves in Fig. 1 are derived for a two-car train with cars of weight and dimensions similar to those of the Rapid Transit Railway in Manhattan. The length of run is an average for the total Long Island suburban service. It will be noted that the power consumption (watt-hours per ton mile) varies from 39.5 to 63.6, the figure according to Davis' formula being 61 per cent. greater than the Baldwin figure. Moreover if the conditions were such that the average speed of 28.6 miles an hour between stations had to be maintained, the speed-time curve of Davis would be impracticable because of no allowance in coasting to provide for possible delays, etc. Therefore, whereas the Baldwin formula indicates a satisfactory equipment working with very low power consumption, the Davis formula for the same equipment shows relatively a very high power consumption and an impracticable equipment. The necessity of careful investigation of this matter in connection with our problem is apparent.

Application of Formulas:

The essential points which we wish to determine are the schedule speeds which can be obtained with given equipments, the power that will be required to obtain these speeds, and the heating effect on the motors. The value of train resistance is best determined at full speed, or while coasting; but except in the case of long runs most of the power is consumed in accelerating. By comparing actual test runs with plotted runs from start to stop, we get some check on the train resistance formulas, but, what is of more immediate importance, we get a verification of the accuracy of all the elements entering into our calculations.

TABLE 1.

AVERAGE SPEED AND WATT-HOURS PER TON MILE.

COMPARISON OF THEORETICAL RESULTS WITH ACTUAL TESTS.

G. R. G. H. & M. RY.

(Schedule speed the same.)

Two Westinghouse No. 50-C Motors. Weight of train 29.5 tons.

Test No.	Davis		Smith		Test	
	Miles per hour	Watt-hours per ton mile	Miles per hour	Watt-hours per ton mile	Miles per hour	Watt-hours per ton mile
1	27.9	98.	27.9	79.2	27.9	88.2
2	32.7	99.2	32.7	81.6	32.7	81.
3	30.4	85.7	30.4	75.0	30.4	86.2
4	30.4	115.1	30.6	111.5	30.6	110.

D. Y. A. A. & J. RY.

(Schedule speed the same.)

Four Westinghouse No. 76 Motors. Weight of train 32 tons.

Test No.	Davis		Smith		Test	
	Miles per hour	Watt-hours per ton mile	Miles per hour	Watt-hours per ton mile	Miles per hour	Watt-hours per ton mile
5	28.3	99.	28.3	94.	28.3	99.
6	31.5	102.	31.5	96.	31.5	105.
7	33.4	95.	33.4	89.	33.4	97.

ARNOLD & POTTER TESTS.

(Power cut off at same distance from start. Schedule speed not the same.)

8 G. E. No. 55 Motors.

Test No.	Weight Train Tons	Davis		Smith		Test	
		Miles per hour	Watt-hours per ton mile	Miles per hour	Watt-hours per ton mile	Miles per hour	Watt-hours per ton mile
8	228.5	26.6	87.	27.6	72.	27.1	79.4
9	201.5	27.7	98.5	28.4	84.5	28.4	82.
10	175.5	29.2	102.	30.9	84.	29.9	86.9
11	148.5	29.6	111.	30.6	89.5	30.6	93.4

To effect a comparison of theoretical results with actual tests, some special tests were made on the Grand Rapids, Grand Haven and Muskegon Railway, and on the Detroit, Ypsilanti, Ann Arbor & Jackson Railway in Michigan. These tests were necessarily confined to trains of one car each. The tests reported by Messrs. Arnold and Potter, made at Schenectady, were on trains of greater lengths. To supplement the single-car

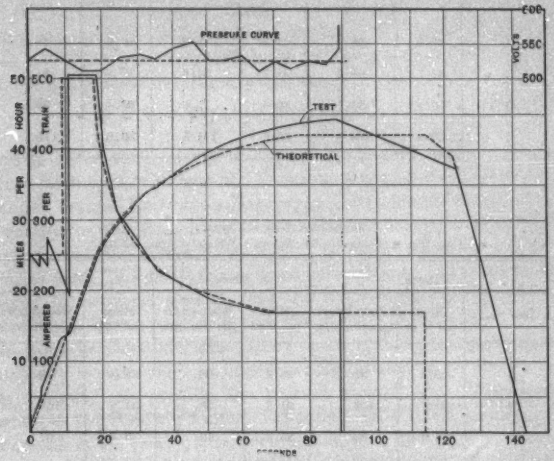


FIG. 2.
Test No. 2—G. R. G. H & M. Ry.

	Results. *Plotted.*	*Test.*
Time, seconds	144	144
Distance, miles	1.31	1.31
Schedule speed miles per hr	32.7	32.7
Kilowatt-hours	3.83	3.13
Watt-hr. per ton mile	99.2	81

Single car; weight 29.5 tons; 2 Westinghouse No. 50 C. Motors.
Davis formula used in plotting run.
Note — Theoretical speed curves are corrected for variations in grade and pressure.

data of trains of identical composition and equipment, theoretical runs were plotted for comparison with some of these Schenectady tests. The various comparisons made are summarized in Table 1, which, therefore, shows the comparison of theoretical and actual results for trains of from one to eight cars per train.

On the G. R. G. H. & M. road the equipment consists of two 150-h.p. motors mounted on a heavy Baldwin truck with Gibbs suspension. The unequipped truck is also of the Baldwin make and the entire equipment is of the highest standard. On the D. Y. A. A. & J. road the equipment consists of four 75-h.p. motors mounted on rather light trucks. Both roads have first-

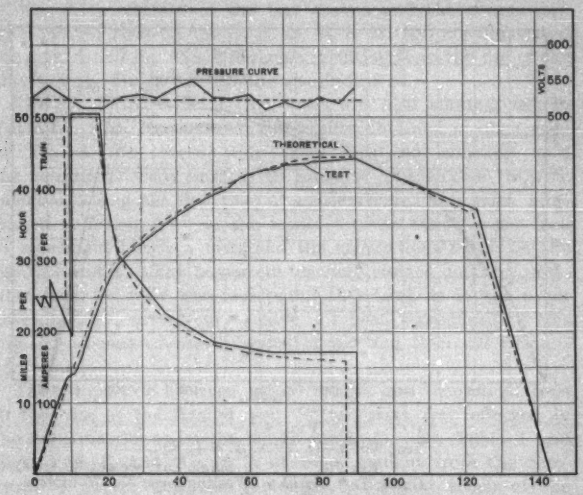


FIG. 3.
Test No. 2—G. R. G. H. & M. Ry.

	Results. *Plotted.*	*Test.*
Time, seconds	144	144
Distance, miles	1.31	1.31
Schedule speed miles per hr.	32.7	32.7
Kilowatt-hours	3.16	3.13
Watt hr. per ton mile	81.6	81

Single car; weight 29.5 tons; 2 Westinghouse No. 50 C. motors.
Smith formula used in plotting run.
Note — Theoretical speed curves are corrected for variations in grade and pressure.

class roadbeds, well ballasted, and laid with 70-lb. rails of standard A. S. C. E. section. The tests were made on sections of track practically straight and level. A chronograph was used to determine the speed at every revolution of the wheels, and the current and pressure were read by observers simultaneously at

five-second intervals. From these tests speed-time and current-time curves were plotted. In making these tests the instructions were to accelerate and brake at as high a rate as practicable; therefore, the curves obtained may be considered as representing the best results obtainable in practice with the existing conditions.

For comparison with these actual results, theoretical runs

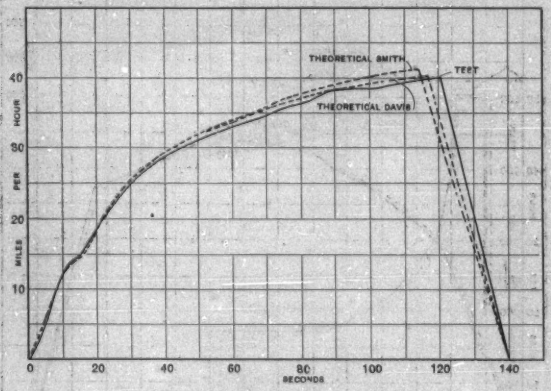


FIG. 4.

Test No. 5—D. Y. A. A. & J. Ry.

	Results.		
	Davis.	*Test.*	*Smith.*
Time, seconds	140	140	140
Distance, miles	1.1	1.1	1.1
Schedule speed miles per hr.	28.3	28.3	28.3
Kilowatt-hours	3.49	3.49	3.33
Watt-hr. per ton mile	99	99	94

Single car; weight 32 tons; 4 Westinghouse No. 76 motors. *Davis* and *Smith* formulas used in plotting runs.

Note—Power cut off at same distance from start. Average speed between stops maintained constant by varying braking rate.

Theoretical speed curves are corrected for variations in grade and pressure.

were plotted in which the length of run was made the same, the average speed was made the same where possible, and the average rate of braking was assumed to be the same as in the actual experiments. The curves were corrected for pressure and grade so as to conform as closely as possible to the conditions prevailing during the test. The observed current readings were plotted and also the assumed theoretical values of

the current corresponding to calculated speeds. The watt-hours per ton-mile were calculated from the observed tests either from wattmeter readings or by multiplying together the simultaneous voltmeter and ammeter readings. In the case of calculated runs, the value was obtained by integration, proper allowance being made for variation in pressure. The results of all the various tests are shown in Table 1.

The characteristics of the test curves and the comparison with plotted runs on the G. R. G. H. & M. Ry. are illustrated by Figs. 2 and 3. The differences resulting from the use of the Davis or the Smith formula are also indicated.

The D. Y. A. A. & J. Ry. tests are also summarized in Table 1. The character of the results obtained is illustrated in Fig. 4. In these tests there was no coasting and the conditions were such as to cause a considerable drop in pressure during the first part of acceleration. This may have caused sufficient error in the readings to account for the lack of agreement between tests and the calculations based on the Smith formula. The power curves were plotted and the watt-hours per ton-mile were computed therefrom as in the other cases, but the current curves have not been reproduced in this Fig. on account of the difficulty of plotting them all without confusion.

The comparison between actual results and theoretical runs in the case of the Arnold and Potter tests was effected in the same manner as for the single car tests. See Table 1 and Figs. 5, 6, 7, and 8. It is at once evident from the comparative curves and the table of results that either of the two formulas for train resistance is reasonably close to the actual conditions. The exhibits when analyzed lead to the following conclusions as to the relative applicability of the two formulas:

The acceleration curve from the Davis formula conforms more closely to the tests for the D. Y. A. A. & J. car, but for the G. R. G. H. & M. car and for the Arnold and Potter trains it falls below the actual curve, in some cases to such an extent that the theoretical schedule speed is below the actual even with coasting eliminated. The Smith formula gives accelerations practically coincident with the G. R. G. H. & M. tests and somewhat higher than the actual for the other tests, the difference in any case not being sufficient to be misleading in the results as to schedule speed. This difference may easily be accounted for by difference in pressure or inaccuracies in ob-

servation of instruments. In the case of the D. Y. A. A. & J. car the type of trucks and the drops in pressure may either of them have caused the reduced acceleration. In the case of the Arnold and Potter tests the most decisive point in the comparison is the fact that, under the prescribed condition of cutting off power at the same distance from the start and making the same length of runs in the same time, to follow the Davis formula would not only necessitate the elimination of coasting

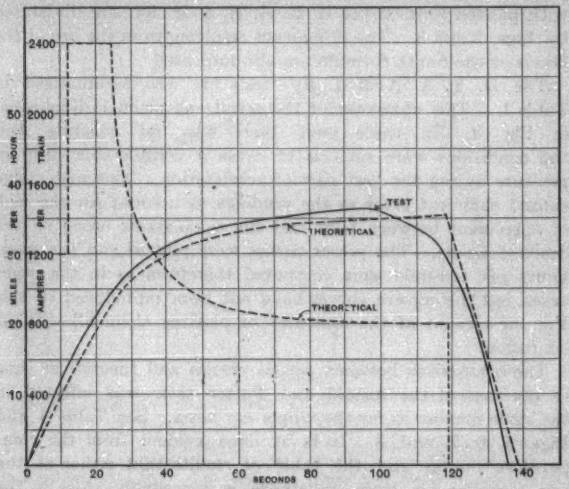


FIG. 5.

Test No. 8—Arnold & Potter. Run No. 1.

Results.		8 cars; weight 228.5 tons; 8 G.E.
Plotted.	*Test.*	No. 55.
Time, seconds..... 138	135.5	*Davis* formula used in plotting run.
Distance, miles.... 1.02	1.02	Head wind, 15 miles per hr.
Schedule speed miles per hr..... 26.6	27.1	Average pressure, 570 volts.
Kilowatt-hours.... 20.3	18.5	Starting current, 300 amperes per motor.
Watt-hr. per ton mile..... 87	79.4	by wattmeter.

but would require braking at a practically impossible rate. In other words, if the Davis formula be correct the trains could not have made the runs in the time that they actually did make. The conclusion, therefore, is that the Smith formula most nearly represents the actual train resistance for all of these tests.

With reference to power required, the actual results appear to fall between the results obtained with either of the two formulas. The calculations based on the Smith formula are closer to the actual results in most cases. For the G. R. G. H. & M. car, where the acceleration curves agree, the watt-hours per ton mile are also very close, and in the Arnold and Potter tests

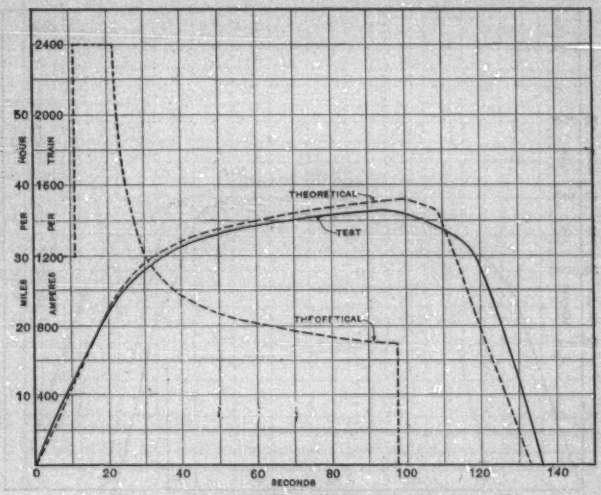


FIG. 6.

Test No. 8—Arnold & Potter. Run No. 1.

	Results. *Plotted.*	*Test.*
Time, seconds	133	135.5
Distance, miles	1.02	1.02
Schedule speed miles per hr.	27.6	27.1
Kilowatt-hours	16.7	18.5
Watt-hr. per ton mile	72	79.4

8 cars; weight 228.5 tons; 8 G.E. No. 55.
Smith formula used in plotting run.
Head wind, 15 miles per hr.
Average pressure, 570 volts.
Starting current, 300 amperes per motor.
by wattmeter.

even with a reduced schedule speed the watt-hours per ton-mile are considerably greater for the Davis formula than for the observed tests. The conclusion reached is that the Smith formula affords a better basis for calculating the average speeds, and is sufficiently close for the determination of power required. Furthermore the comparative results with these vari-

ous train weights and types of motor, give us a confidence in all the assumptions made and in the customary use of the motor curves and other data furnished by the manufacturers.

Test of Equipment Similar to that Proposed for the Long Island Railroad.

Through the courtesy of the Interborough Rapid Transit

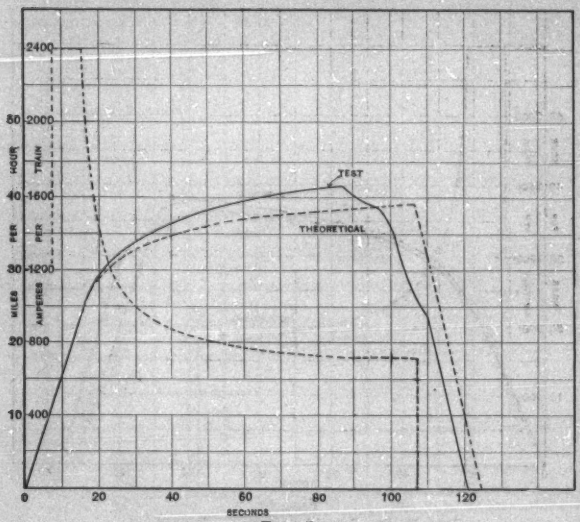


Fig. 7.

Test No. 11—Arnold & Potter. Run No. 7.

	Results. *Plotted.*	*Test.*
Time, seconds.....	124	120
Distance, miles....	1.02	1.02
Schedule speed miles per hr.....	29.6	30.6
Kilowatt-hours....	16.7	14.3
Watt-hr. per ton mile.....	111	93.4 by wattmeter.

5 cars; weight 148.5 tons; 8 G.E. No. 55 motors.
Davis formula used in plotting run.
Head wind, 15 miles per hr.
Average pressure, 570 volts.
Starting current, 300 amperes per motor.

Company and Westinghouse Electric & Manufacturing Company it is possible to present the record of a special test which has a direct bearing on this subject, because the type of motor equipment used in the test is the same electrically as that recommended for the L. I. R.R. project. On January 30, 1903,

a test was made on the Ninth Avenue line of the Manhattan Elevated Railway, of the sample motors submitted by the Westinghouse Electric & Manufacturing Company as representing the motors which that company was to furnish to the Interborough Rapid Transit Company. In these tests the train weight corresponded closely with the weight per motor of the

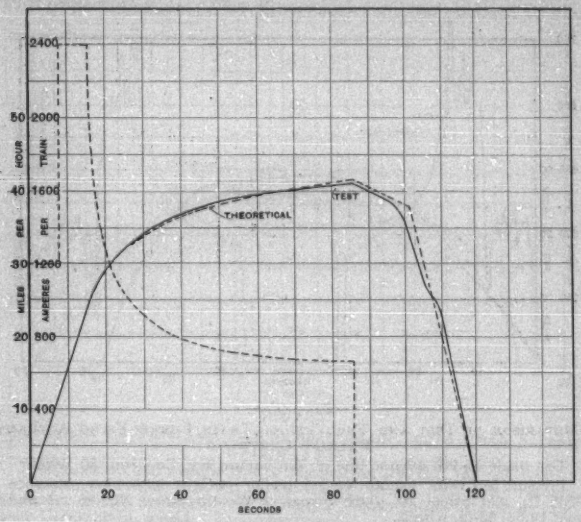


FIG. 8.

Test No. 11—Arnold & Potter. Run No. 7.

Results.	*Plotted.*	*Test.*
Time, seconds.....	120	120
Distance, miles....	1.02	1.02
Schedule speed miles per hr.....	30.6	30.6
Kilowatt-hours....	13.5	14.3
Watt-hr. per ton mile.....	89.5	93.4

5 cars; weight 148.5 tons; 8 G.E. No. 55.
Smith formula used in plotting run.
Head wind, 15 miles per hr.
Average pressure, 570 volts.
Starting current, 300 amperes per motor.
by wattmeter.

equipment proposed for the L. I. R.R. and the motors were of the same size and general characteristics. The length of the test run was too short to permit the cars to reach maximum speed; as the value of train resistance is best determined at maximum speed, this test cannot by itself be considered an absolute check on calculated curves.

When viewed in the light of tests of other equipment on longer runs, however, it affords a good indication as to how close this specific equipment will conform to the theoretical basis of our determinations. The results of this test are given in Figs. 9 and 10. Fig. 9 gives the results of a north-bound run between 93d Street and 104th Street, and Fig. 10

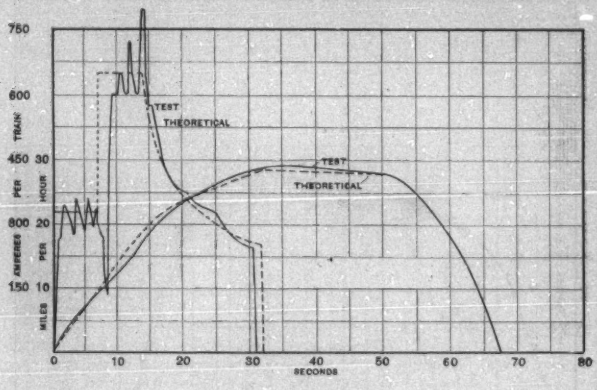


FIG. 9.

COMPARISON OF TEST AND THEORETICAL TRAIN CURVE USING ACTUAL BRAKING CURVE.

Test made on 9th avenue line of Manhattan Ry. Co., Jan. 30, 1903.

Pressure 580 volts; 1 motor car; 1 trailer; weight 62.5 tons; distance 2065 ft., 93d Street to 104th Street; 2 Westinghouse No. 86 motors; gear 19:63; 33-in. wheels.

	Results.	
	Test.	*Theoretical.*
Average speed without stop	20.9	20.9
Schedule speed with 15 sec. stop	17.05	17.05
Kilowatt-hours per run	1.93	2.13
Kilowatt-hours per car mile	2.475	2.72
Watt-hours per ton mile	79.3	87.2
Average kilowatts per train	84.3	92.9
Sq. root mean sq. current per motor for 85 sec.	149.0	157.5
Starting current per motor	294.	325.

Smith formula used in plotting run.

gives results for a south-bound run on the same section of road. Actual results are indicated by the solid lines, and for comparison there are given on the same Figs., theoretical curves calculated for the corresponding conditions, the train resistance formula and the methods used in the

calculations being the same as for the other exhibits hereof and for all L. I. R.R. determinations. In these tests the braking rate was not constant but increased as the speed decreased, and for comparison the same braking curve was assumed for the theoretical as for the test runs.

The results in these comparative curves are tabulated under the respective FIGS. The theoretical run was plotted to ob-

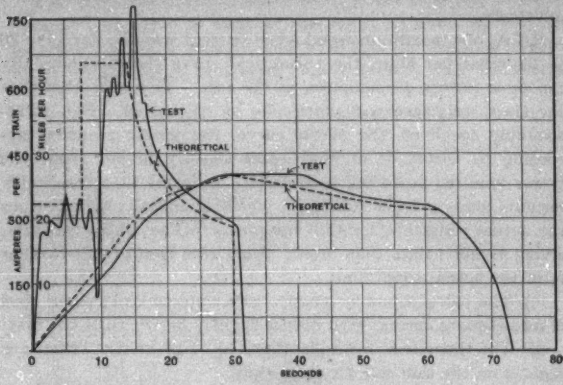


FIG. 10.

COMPARISON OF TEST AND THEORETICAL TRAIN CURVE USING ACTUAL BRAKING CURVE.

Test made on 9th avenue line of Manhattan Ry. Co., Jan. 30, 1903.

Pressure 580 volts; 1 motor car; 1 trailer; weight 62.5 tons; distance 2090 ft., 104th Street to 93d Street; 2 Westinghouse No. 86 motors; gear 19:63; 33-in. wheel.

	Results.	
	Test.	*Theoretical.*
Average speed without stop	19.32	19.32
Schedule speed with 15 sec. stop	16.10	16.10
Kilowatt-hours per run	1.91	2.06
Kilowatt-hours per car mile	2.415	2.65
Watt-hours per ton mile	77.0	83.0
Average kilowatts per train	77.3	82.5
Sq. root mean sq. current per motor for 85 sec.	145.2	157.0
Starting current per motor	300.0	325.0

Smith formula used in plotting run.

tain the same average speed as the test. This involved assuming the power applied for a longer period than the test in one case and a shorter period in the other. In both cases, however, it will be noted that the power requirements (watt-hours per ton-mile) and the square root of mean square current

are greater for the theoretical run than for the test. Furthermore, it will be noted that the average starting current per motor was less in the test than in the theoretical run. The conclusions derived from this exhibit are as follows:

(a) The motor control did not permit of the rapid application of power assumed in the calculations, time being lost in going from series to parallel. This, however, did not affect the results adversely.

(b) At the maximum speed when current was on, namely, 26 to 28 miles per hour, the theoretical curve shows practically the same energy consumption as the test. This indicates that the train resistance was practically as calculated. For corresponding speed on the motor curve, the power required according to theory is in both cases slightly higher than the power required according to test; this indicates that the Smith formula gives a train resistance which is slightly higher than the actual resistance for this equipment. The Davis formula, giving higher values than Smith would give results still further from the actual conditions.

(c) The calculations for energy consumption and square root of mean square current give results slightly higher than the test.

(d) The theoretical methods, therefore, give values which are slightly on the safe side for short runs.

(e) The tests do not afford direct evidence of the accuracy of the theoretical methods when applied to longer runs with higher speeds, but the indications are that for such runs the theoretical values will also be on the safe side and close enough for all practical purposes.

II. Use of Typical Run Curves:

As previously stated, the proposed electrical schedule for the Long Island Railroad provides for a large number of combinations of weights of trains and lengths of run. It is obvious that a very great amount of time would be consumed if an attempt were made to plot each of these runs and to make the determinations of schedule speed, power consumption, and heating effect for the various types and sizes of motors which might be used. To avoid this expenditure of time it was necessary to adopt certain approximate methods, and one method which was used after verification by a practical comparison, is what may be called the "Typical Run Curve."

Disregarding grades and curves, a single run for a distance

equal to the average length between stops will represent the conditions pertaining to a through run; by plotting results for such average runs of different lengths, curves are obtained which will give exact results for the actual conditions assumed, and approximate results for the varying distances between stops and on a succession of light grades and curves. Fig. 11 illustrates the character of the curves obtained in this way.

The principal question involved as to the propriety of such a typical run curve is whether the result so obtained (by considering the track straight and level and the distance between all stops the same) will agree closely enough with the average

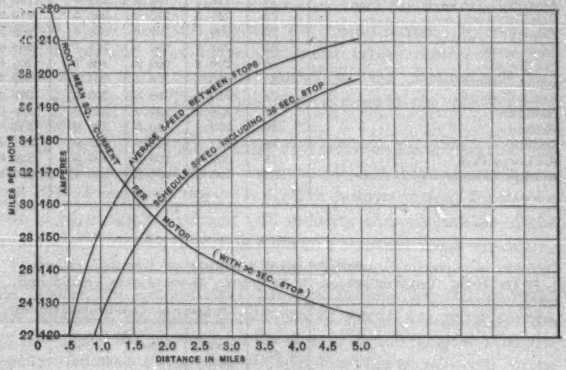

MILES PER HOUR
AMPERES
DISTANCE IN MILES
ROOT MEAN SQ. CURRENT
AVERAGE SPEED BETWEEN STOPS
SCHEDULE SPEED INCLUDING 30 SEC. STOP
MOTOR
(WITH 30 SEC. STOP)
0 .5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0
220 210 200 190 180 170 160 150 140 130 120

FIG. 11.

GENERAL PERFORMANCE CURVE.

3-car train for L. I. R.R.; two 44-ton motor cars; one 33-ton trailer car; total weight 121 tons; four No. 86 Westinghouse motors; 23:59 gear ratio; 36-in. wheel; 540 volts; 1.5 miles per hr. per sec. braking; no coasting.

of results obtained from plotting the time-speed curves of an entire round trip, taking the grades and curves into account and placing the stops exactly. It would seem reasonable that the effects of grades in one direction should balance those in the opposite direction when calculating the general results of a run plotted for a round trip, when the time of a single run is not greater than one hour, as in this case. If the results of train runs plotted complete be compared with typical run curve results, and if this comparison is generally favorable under

TABLE 2.

ROCKAWAY PARK DIVISION.

77-ton Train. Two Westinghouse No. 86 Motors. 30-second stop. No Coasting.

Run.	Length of Run	Square root of mean square current.			
		Plotted Run East	Plotted Run West	Average Plotted Both Ways	Typical Run.
Long Island City					
Bushwick Junction	3.92	154.5	137.3	145.9	147.9
Fresh Pond Junction	.46	223.9	227.0	225.4	226.8
Glendale Junction	1.61	178.2	179.0	178.6	179.3
Brooklyn Hills	.65	241.7	220.5	231.1	215.0
Woodhaven Junction	.97	186.5	207.0	196.7	200.2
Ozone Park	.30	227.0	274.0	250.5	240.0
Aqueduct	1.34	176.0	192.0	184.0	186.8
Ramblersville	.73	201.5	210.5	206.0	210.0
Howards	.76	209.5	207.0	208.2	209.3
Goose Creek	.93	201.7	200.5	201.1	201.8
The Raunt	.96	200.5	209.8	205.1	200.6
Broad Channel	.83	205.7	203.5	203.1	205.7
Beach Channel	.74	210.5	208.5	209.5	209.9
Hammel	.47	225.0	231.0	228.0	226.0
Holland	.39	229.5	210.5	220.0	232.0
Seaside	.49	227.5	224.5	226.0	229.4
Rockaway Park	.75	209.5	209.6	209.5	209.6
Average for round trip	.948	199.0	201.9	200.45	201.2

TABLE 3.

NORTH SIDE DIVISION.

77-Ton Train. Two Westinghouse No. 86 Motors. 30-second stops. No Coasting.

Run.	Length of Run	Square root of mean square current.			
		Plotted Run East	Plotted Run West	Average Plotted Both Ways	Typical Run.
Long Island City					
Woodside	3.04	165.5	150.1	157.8	156.
Winfield	1.00	194.0	202.7	198.3	199.
Elmhurst	.81	210.5	202.0	206.2	207.
Corona	.92	215.0	210.0	212.5	202.
Whitestone Junction	1.20	179.8	195.8	187.8	191.5
Flushing, Main Street	1.98	209.9	195.0	202.4	171.5
Murray Hill	.90	237.0	195.5	216.2	203.
Broadway	.54	223.9	218.0	220.5	221.
Auburndale	.78	224.0	226.0	225.0	208.
Bayside	.97	208.5	202.0	205.2	200.
Douglaston	1.26	174.0	186.0	180.0	180.3
Little Neck	.55	233.0	225.0	229.0	220.5
Great Neck	1.24	199.3	165.5	182.4	190.
Manhasset	1.53	202.8	202.0	202.4	181.3
Port Washington	2.66	168.0	158.0	163.0	160.5
Average sq. root mean sq. for whole run	1.20	198.0	191.5	195.0	191.0
Average for round trip		24.2	24.9	24.55	24.

varying conditions of grade and length of run, it is safe to assume that typical run curves can be used in place of plotted runs for purposes of general estimate and comparison of different types of equipment when operated under similar conditions. The comparisons have, therefore, been made for a given equipment by making plotted runs in opposite directions over the same grades on certain routes of the Long Island R.R. both on the comparatively level runs of the Manhattan Beach and Rockaway Beach divisions and on the more hilly runs from Long Island City to Port Washington. Tables of two of these runs are appended hereto (Tables 2 and 3), which give values for the square root of mean square current for individual runs between stops and the average for round trips. It is to be noted in passing that these particular tables represent motor performances that proved too heavy for the motors and had to be abandoned. They, however, illustrate the point under discussion.

It is possible to make similar comparisons for kilowatt-hours per car-mile and watt-hours per ton-mile, but it is safe to assume that a check made on the comparative determinations for square root of mean square current will indicate the correctness of the assumptions for the determination of the other requirements.

In general it will be noted that the differences between typical run results and the plotted runs, even in the case of the North Side Division, on which conditions of grade are most severe, do not exceed five per cent. for the square root of mean square current and about four per cent. for speed. This would seem to be sufficiently close for practical purposes in making estimates for given equipment operated over runs of varying lengths where grades are so comparatively light as in the case of the Long Island R.R.

A verification of the accuracy of this method for power determinations in service on an interurban road of the normal amount of curvature in a comparatively level country is obtained by plotting an average run for the G. R. G. H. & M. road, Fig. 12 shows a run plotted for the same distance, time, initial acceleration, and percentage of time coasting and braking as averaged on a round trip service run of a single car of the G. R. G. H. & M. Ry. outside of terminal cities. The tabulated data under this Fig. shows that the watt-hours per ton-mile were within six per cent. of the same value for the theoretical average as for the observed average of an actual test.

The foregoing examples demonstrate that for preliminary determinations of motor characteristics, reasonably close results are obtained by assuming a typical run, except possibly where very unusual conditions exist. No claim is made that the method is new; in fact it is quite generally used. The data given simply show that under ordinary circumstances it is reasonable to use this short method and thus dispense with a large amount of tedious calculating.

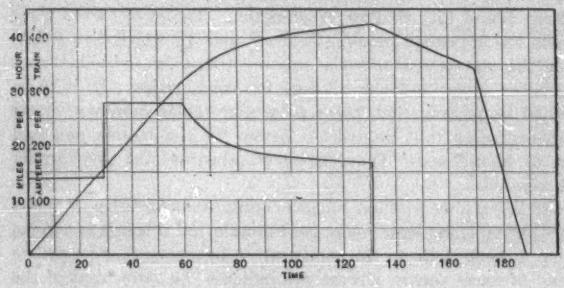


FIG. 12.

AVERAGE PERFORMANCE IN SERVICE, OF G. R. G. H. & M. RY. CAR.

Two Westinghouse 50 C. motors; 20:51 gear ratio; 0.55 miles per hr. per sec. initial acc.; 525 volts; 140 amperes per motor starting current; weight 29.5 tons; average grade, level.

	Results.	
	Theoretical.	*Observed average.*
	G. R. G. H. & M. Ry.	
Distance, miles	1.54	1.54
Time, seconds	188	188
Schedule speed miles per hr.	29.5	29.5
kilowatt-hours	3.84	3.65
Watt-hr. per ton mile	84.5	80.3
Root mean sq. current, amperes	95.6	

Smith Formula.

III. SCHEDULE SPEED REQUIREMENTS AND LIMITATIONS:

The operating conditions of a large steam railroad introduce limitations which cut down the possible speed of the motive power equipment. Many of these are conditions which do not relate to the nature of the equipment and over which the locomotive engineer has no control; for instance, curves, road crossings, junction points, yard limitations, meeting points on single track lines, time to handle baggage and express matter,

etc. There are delays at stations and delays during runs, some of which occur regularly, but many of which are intermittent. Because of the complicated service these delays are greater on the suburban lines of a steam road than usually occur in interurban or elevated electric service. It is, therefore, evident that in the electrical operation of such suburban service the loading of the motors will differ materially from the loading in an ideal run which might be made with the conditions removed.

After considering various methods of providing for these conditions it was decided to make a series of tests of the

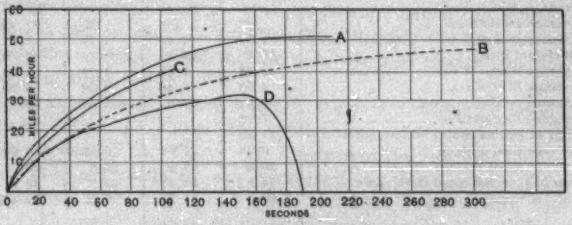


FIG. 13.

TIME-SPEED CURVE OF 3-CAR STEAM TRAIN.

A.—From best locomotive performance reduced to level. Weight of train, including locomotive No. 59, 171.9 tons disregarding light live load. Weight of locomotive, including tender, 88.5 tons. Weight on drivers, 37.5 tons.

TIME-SPEED CURVE OF 5-CAR STEAM TRAIN.

B.—From best locomotive performance reduced to level. Weight of train, including locomotive No. 64, 232.6 tons disregarding light live load.

TIME-SPEED CURVE OF 3-CAR STEAM TRAIN.

C.—From actual run made on a level. Weight of train, including locomotive No. 72, 175.1 tons, disregarding light live load.

TIME-SPEED CURVE OF 5-CAR STEAM TRAIN.

D.—From actual run made on a level. Weight of train, including locomotive, No. 64, 232.6 tons disregarding light live load.

present steam equipment to determine the speed time characteristics of the steam trains and the degree to which these characteristics are affected by the local conditions. To this end a test car was equipped with a speed-recording device and runs were made over various routes with this car attached to regular trains. Complete records were obtained of the movement of each train throughout a round trip, and observations made of local conditions which affect speed. These records were carefully analyzed and the results tabulated. In some instances

TABLE 4.
LONG ISLAND RAILROAD.
LONG ISLAND CITY TO VALLEY STREAM VIA FAR ROCKAWAY. EASTBOUND.
Length of Run, 22.97 miles.

Train Number.	1287	1303	1321	Average
Locomotive number	72	34		
Locomotive weight	179,000	154,500		
Number of cars	3	4	5	4
Total weight of train (tons)	175.1	186.55		
Schedule time of run	56 :00	55 :00	58 :00	56 :00
Actual time of run	52 :30	74 :20	59 :00	62 :00
Schedule number of stops	9	10	12	10
Actual number of stops	10	11	12	11
Maximum acceleration	.6	.7	.65	.65
Grade on which made	−1.00	−0.08	−0.08	−0.38
Maximum retardation	1.6	1.8	1.9	1.76
Grade on which made	Level	Level	Level	Level
Average acceleration	.47	.46	.35	.426
Average retardation	1.04	1.06	1.22	1.11
Maximum speed	56.5	52.5	50.	53.
Average length of run	2.08	1.91	1.77	1.92
Average time of run	4 :03	4 :48	4 :10	4 :20
Average maximum speed	39.9	34.8	33.5	36.1
Length of longest run	7.77			
Time of longest run	11 :20			
Average time of stops	0 :49	1 :55	0 :25	0 :63
Average speed between stops	30.8	23.9	25.5	26.
Possible average speed from curve	34.5	33.7	32.7	33.7
Ratio average to possible average speed	89.4%	71.%	76.%	79.6%

TABLE 5.
LONG ISLAND RAILROAD.
WHITESTONE DIVISION. WESTBOUND.
Length of run, 11.75 miles.

Train Number.	346	360	318	Average
Locomotive number	59	35	20	
Locomotive weight	177,000	154,500	139,500	
Number of cars	3	3	5	4
Weight of train (tons)	171.9	162.85	217.85	184.2
Schedule time of run	28 :00	28 :00	31 :00	29 :00
Actual time of run	28 :34	27 :34	35 :15	30 :27
Schedule number of stops	7	7	7	7
Actual number of stops	7	7	7	7
Maximum acceleration	.9	.95	.5	.78
Grade on which made	−0.65	−0.65	−0.75	−0.68
Maximum retardation	1.8	2.0	1.9	1.9
Grade on which made	1.07	0.69	1.28	1.01
Average acceleration	.44	.35	.29	.36
Average retardation	1.43	1.5	1.2	1.38
Maximum speed	52	50	44.5	48.8
Average length of run	1.47	1.47	1.47	1.47
Average time of run	3 :08	3 :14	3 :55	3 :26
Average maximum speed	41	38.3	33.5	37.6
Length longest run			1.63	
Time longest run			3 :47	
Average time at stops	0 :20	0 :15	0 :33	0 :26
Average speed between stops	28.1	27.3	22.5	25.9
Possible average speed from curve	30.8	30.8	30.8	30.8
Ratio actual to possible average speed	91.3%	88.6%	73%	84.2%

the engineers were requested to make the best time possible; in other cases they were not advised that a test was in progress.

In summarizing these test runs comparisons were made between the average speed between stops as actually attained and the possible average speed if best acceleration had been made for each run. The character of record obtained is illustrated in Tables 4 and 5. It was found that the ratio of the actual speed to the possible speed without local limitations is from 71 to 91.3 per cent. Even when the engineers were requested to do their best they were able in only one or two instances to exceed 90 per cent. of the speed which appeared from the test to be possible. On runs 335 and 346 of the Whitestone Division in which locomotive No. 59 made the best single record, the average speed for the run was also nearest to the maximum limit.

From these records were selected the four best single accelerations. Fig. 13 shows the speed-time characteristics of these accelerations. Curve D illustrates the general character of record made by the instrument in these tests. This run, having been made on a level, conforms exactly with the record obtained. Curves A, B, and C were obtained on grades, and the actual record has been corrected to illustrate the performance of these trains when reduced to a level. In each case the average acceleration over the run was less than the characteristic shows, but these curves illustrate the maximum that the steam equipment was able to do. The composition of trains and their estimated weights are indicated under Fig. The live load on these runs was so light that it was disregarded. On Fig. 14 will be found two curves (E and F) of actual runs on grades, compared with run A of the Fig. 13. According to curve E, a five-car train on a down grade was accelerated at a rate far below the best performance and even the three-car train with locomotive No. 35 (curve F) was not accelerated on a down grade with a rate any better than the best single performance on a level.

It will be noted that the curve *A* was made by a locomotive whose weight was 51.5 per cent. of the total weight of train. The officials of the railroad were of the opinion that service equivalent to that which could be performed by this locomotive, No. 59, with only three cars would be a sufficient for the electric equipment. The best performance of this locomotive was, therefore, taken as the criterion by which to work in de-

termining the proper characteristics for the electric equipment. The condition laid down was that the electrical equipment, operating a train with standing load in the cars, should be able to make the same average speed between stops as this particular steam equipment.

Taking curve *A* as a basis, determinations were made of what may be termed the "speed-limit" for steam trains. This is a curve indicating the average speed in miles per hour between stops with the rate of acceleration corresponding to curve *A*, without coasting, and with a braking rate of 1.5 miles per hour per second. On Fig. 15 there will be found

FIG. 14.

TIME-SPEED CURVE OF 3-CAR STEAM TRAIN.

A.—Taken from curve sheet No. 13.

TIME-SPEED CURVE OF 5-CAR STEAM TRAIN.

E.—From College Point to Whitestone, made by 5-car steam train. Weight, including locomotive No. 18, 276.1 tons disregarding small live load. Acceleration made on average grade of –0.78 per cent.

TIME-SPEED CURVE OF 3-CAR STEAM TRAIN.

F.—From Whitestone to College Point, made by 3-car steam train. Weight, including locomotive No. 35, 162.85 tons, disregarding small live load. Acceleration made on average grade of –0.74 per cent.

a characteristic speed-time curve of this steam train making runs of from one mile to three miles. From this curve the speed-limit curve No. 16 was plotted. Table No. 6 shows how this speed-limit of steam trains compares with the average speed between stops required to make various typical runs of the proposed suburban service. It will be noted that the average speed of the schedule runs is from 71.2 to 92 per cent. of the speed limit, with about 80 per cent. as a mean figure.

SCHEDULE CONDITIONS OF PROPOSED ELECTRIC SERVICE:

Obviously, to make the same time, the speed characteristics of the electric equipment selected for this service must be such

TABLE 6.

DATA FOR SUBURBAN RUNS. L. I. R.R.

OMITTING RUNS WHERE NUMBER OF STOPS IS SAME AS HEREIN BUT TIME AT STOPS IS LESS.

Run.	Distance miles.	Time minutes.	Train sheet schedule speed entire run.	Intermediate No. of stops per trip.	Time out for stops.	Average Length of Run miles.	Time of average Run minutes.	A. Average speed between stops miles pr hr	B. Limit av. speed best steam train miles pr hr	Ratio of $\frac{A}{B}$ steam.	C. Limit average speed electric train 23:59 gear ratio.	Ratio $\frac{A}{C}$ Electric.
Long Island City.		41.5	26.3	7	4.5	2.27	4.62	29.5	36.0	81.9	35.5	83.2
Port Washington.	18.18	43.0	25.4	8	5.0	2.02	4.22	28.7	34.0	84.4	34.0	84.5
Long Island City.												
Whitestone Landing.	11.75	31.0	22.8	7	3.5	1.47	3.44	25.6	30.8	83.2	31.8	80.5
		39.25	24.9	5	2.5	2.72	6.12	26.7	37.5	71.2	36.5	73.2
		39.0	25.1	6	2.75	2.33	5.18	27.0	36.0	75.0	35.5	76.1
		40.0	24.4	7	3.5	2.04	4.57	26.8	34.0	78.8	34.0	78.8
Long Island City.		41.0	23.8	8	4.25	1.81	4.08	26.6	33.0	78.8	33.5	79.5
Rockaway Park.	16.3	43.0	22.8	10	4.0	1.48	3.55	25.0	30.8	81.2	31.8	78.7
		43.75	22.3	11	4.5	1.36	3.27	25.0	30.0	83.3	31.0	80.7
		47.0	20.8	14	5.5	1.09	2.76	23.7	27.0	88.0	29.0	81.8
Long Island City.												
Valley Stream.	22.97	59.5	23.1	11	7.5	1.91	4.33	26.4	33.7	78.4	33.7	78.3
		37.0	26.1	3	3.0	4.03	8.5	28.5	41.0	69.5	39.0	73.0
		38.0	25.4	4	2.5	3.22	7.1	27.2	39.0	69.8	37.5	72.6
Long Island City.		40.0	24.2	5	3.75	2.68	5.87	27.4	37.5	73.2	36.5	75.0
Manhattan Beach.	16.1	44.0	22.0	11	6.5	1.34	3.12	25.8	29.8	86.5	31.3	82.5
		39.5	24.5	7	4.0	1.98	4.56	26.0	34.0	76.5	34.0	76.5
		44.75	21.5	11	5.0	1.32	3.31	23.9	29.5	81.2	31.0	77.2
Flatbush.		45.5	20.9	12	5.75	1.22	3.06	23.9	28.5	84.0	30.0	79.6
Rockaway Park.	15.88	47.0	20.2	15	6.5	0.99	2.53	23.5	26.5	88.6	28.5	82.5
		48.0	19.8	16	6.75	0.93	2.43	23.0	26.0	88.5	28.0	82.2
Flatbush.		19.0	30.4	1	1.0	4.81	9.0	32.0	42.5	75.3	40.0	80.0
Jamaica.	9.63	23.0	25.1	5	3.0	1.61	3.33	29.0	31.5	92.1	32.5	89.2
Flatbush.												
Valley Stream.	22.55	60.5	22.4	13	9.0	1.61	3.68	26.1	31.8	82.0	32.0	82.4

that the schedule can be maintained with similar speed reserve, unless the limiting conditions are removed. Some of these conditions are being removed and others probably will be. Elimination of grade crossings at roads and junction points, handling of baggage and express matter by special trains, improvement of yard facilities, etc., will make it possible to operate trains at speeds closer to the limit of the equipment. On the other hand, as the population along the road increases the tendency will be to increase the number of stops with as little increase as possible in the running time; therefore, it was decided not to make any material allowance for improved conditions in the initial service. The probability of such improvement, however, suggests another precaution to be taken in the selection

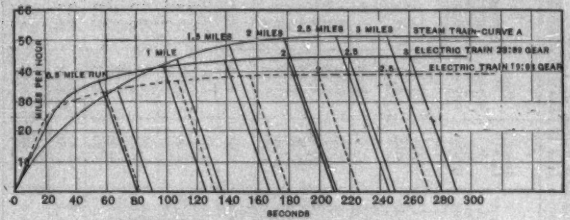


FIG. 15.

TIME-SPEED CURVE OF STEAM TRAIN.
Curve *A* of sheet No. 13.

TIME-SPEED CURVES OF PROPOSED ELECTRIC TRAINS.
Best possible performance on level grade.
Weight of train, 121 tons, without standing load.
(All 3-car trains.)

of equipment; namely, the provision of a suitable reserve in capacity of motors to carry the greater loads which will result from running at speeds closer to the limit.

On Fig. 15 are time-speed curves of a three-car electric train with two motor cars and one trailer, with standing load in the cars, which curves may be compared with the corresponding curve of the steam train on the same Fig. It will be noted that the electric equipment with the lower gear ratio has a maximum speed on straight level track of approximately 45 miles per hour, and with the higher gear ratio, 39 miles per hour; whereas the limit of the steam train on the level is 52 miles per hour. For a run of one mile or less between stops, however, the electric train with either gear ratio

makes better time than the steam train. For a 1.5-mile run the electric train with higher gear ratio falls behind the steam train, and at slightly over two miles the electric train with the lower gear ratio falls behind.

The comparative speeds of these trains are still better illustrated on the speed-limit curves of Fig. 16. The general average length of run between stops for the suburban service is about 1¾ miles. It is evident from the speed-limit curves on curve sheet 16 that a three-car electric train with two motor cars and gear ratio 23:59 will average slightly better as to speed than the three-car steam train, but that the same equipment with higher gear ratio falls considerably below the

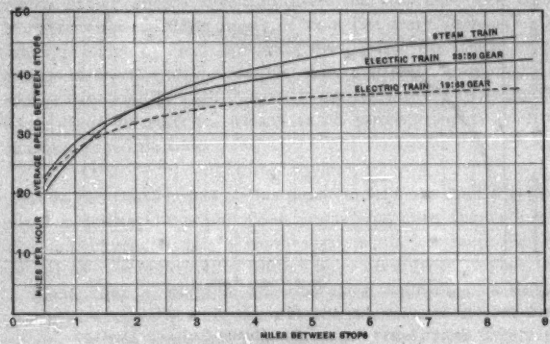


FIG. 16.

SPEED LIMIT CURVES FOR 3-CAR TRAINS.

Showing best possible speed between stops over various lengths of run, without coasting.

Steam train based on curve *A* for acceleration.

Electric train with standing load weighs 121 tons.

speed-limit of the steam train. From this exhibit it is obvious that schedule requirements dictate that no gear ratio higher than 23:59 should be adopted.

It is also evident from these speed-limit curves that if 23:59 is the lowest gear ratio practicable as determined by limitations, the three-car train unit will have to be made up of two motor cars and one trailer, in order that the requisite speeds may be reached. The weight per motor for this equipment is 30.3 tons, which on this basis of speed requirements is

obviously close to the limit. This is also made evident by the speed-limit curves of Fig. 17. In this case a two-car train is made up of one motor car and one trailer. It will be noted that such an electric train, with standing load, falls below the speed-limit of the steam train at slightly over one mile between stops. As regards speed requirements, therefore, the two-car train with motor car and trailer has not sufficient motor capacity, and except in cases where speed limitations are slight, two-car trains will have to be made up of two motor cars in

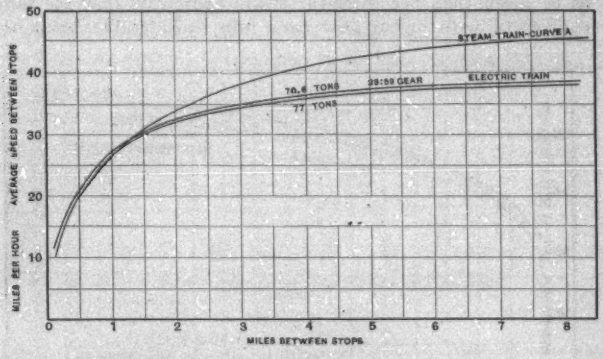


FIG. 17.

SPEED LIMIT CURVES FOR MOTOR CAR AND TRAILER.
Compared with steam train.
Electric train weighs 70.6 tons, seated load.
Electric train weighs 77 tons, standing load.
Steam train based on curve *A* for acceleration.

order to make the schedule. On this Fig. 17, the corresponding curve for train with seated load has been plotted to indicate the difference in schedule speed possible during the light traffic hours of the day, as compared with the hour of heavy load morning and evening. It will be noted that in the case of heavy equipment of this character the changes in weight of live load do not materially affect the speed characteristics of the equipment.

Attention was called to the column of Table 6 which shows the ratio between the average speed of steam train between stops on different runs according to schedule, and the

speed-limit possible with the best steam train in each case. Another column of this table gives the ratio of average speed to the speed-limit of the three-car electric train for the same runs. It will be noted that the reserve speed in the electrical equipment corresponds closely with the reserve in the steam equipment throughout the list. It, therefore, seems evident that this three-car train unit fulfils the requirements laid down as to speed, and can be depended upon to make the required schedule with standing load in the cars, allowing for all the delays contemplated in the present schedule for steam equipment.

It is obvious that trains made up into combinations of motor-cars and trailers that give less weight per motor will be able to make better speeds than indicated for this three-car train. Furthermore, as the number of cars per train increases, the relative effect of head resistance decreases. For these longer trains it is, therefore, possible that a greater proportion of trailer cars may be used in some instances without reducing the speed-limit to such an extent as to prevent the train from making schedule time.

Conclusion.

It is not the purpose of this paper to follow out all the technical processes by which final conclusions were deduced as to size and characteristics of motor equipments for the project referred to. Sufficient illustrations have been given to show:

First, that a study of the operating conditions of even a complex project quickly narrows the selection of motors down to one or two sizes, and that these conditions also largely determine the speed characteristics of the equipment; *secondly*, methods of computation are now developed to a point of sufficient accuracy to be considered reliable for purposes of selecting equipment; *thirdly*, short methods may be used with discrimination, at least for preliminary determinations.

With reference to the use of short methods, a remark may be made in closing regarding the advantage to be gained by deriving a set of general formulas, applicable to all sizes of motors. On first consideration, such a problem as herein described makes such data seem almost indispensable. When we find that only one or two sizes of motor need be considered, however, the advantage of so general a method becomes less apparent. On the other hand, with a little ingenuity, graphical or mechanical methods may be devised for plotting characteristic curves, which make it possible to determine the values of speed,

current, etc., throughout a complete run with surprising rapidity. At the present state of development, therefore, it appears that the most satisfactory results may be obtained by employing the characteristics of a specific equipment rather than by spending time in deriving a set of hypothetical characteristics in which many important variables are neglected.

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THE MAXIMUM DISTANCE TO WHICH POWER CAN BE ECONOMICALLY TRANSMITTED.

BY RALPH D. MERSHON.

As transmission voltages, actual or proposed, become higher and higher and transmission distances reach out farther and farther, it is interesting and profitable to inquire into the probable maximum distance to which power will be commercially transmitted. As with most engineering enterprises the limitations will come through economic conditions, and the greatest distance to which power will ever be commercially transmitted is the greatest distance to which it can ever be economically (using the word in its broad sense) transmitted.

In endeavoring to make such a forecast, as will be here attempted, it should be borne in mind that each additional limitation consequent upon the assumptions necessary in order to obtain definite representative figures adds to the chance of the forecast proving erroneous. For instance, the first asumption which must be made is that in the future power will be transmitted in the same way as now. This may not hold. There may be devised some other and better way not involving the use of transmission lines. Such, however, does not appear probable. Other assumptions as to methods of construction being the same as, or similar to, those at present in use may be eventually so modified by skill and experience as to change very materially any conclusions arrived at now. This is less improbable. Conditions, industrial and financial, may so change that the constants now assumed as fixing costs, interest, etc., will be materially modified. This is probable. Finally, it is certain that with the course of

time the value of power will increase, and this will materially alter any figures at which we may now arrive. The present conditions of practice and possibility are sufficiently definite, however, to warrant a forecast with the expectation that it will be applicable, approximately at least, for some considerable time to come. At any rate, the method of treatment of the subject herein adopted will, with suitable changes in the values of constants, apply so long as present methods of power transmission obtain, and makes possible a comprehensive view of the possibilites of long distance transmission.

The elements which, in the broadest sense, limit the distance to which power can be economically transmitted, are two; the cost of power at the generating station, and the price which can be obtained for the delivered power. The difference between these two elements must cover the cost of transmission, the interest on the investment, and the profit. The cost of transmission comprises the loss of power in transmission, the cost of operating, and the cost of maintenance and repair. The value of the sum total of the interest which must be paid upon the investment, and the minimum profit which is considered satisfactory, will have much weight in determining the limiting distance of transmission. The less this sum is the farther power can be transmitted; a low interest rate and a low rate of dividend will, therefore, be conducive to long transmissions.

Let us consider in a general way the manner in which the investment in a transmission plant and the annual charges and expenses in connection with the plant vary with different outputs, voltages, and distances of transmission. For a given voltage, drop, and distance of transmission, the cost of all the apparatus and equipment, except the line conductors, will increase more slowly than the output of the plant. That is, the greater the output of the plant the less the cost per kilowatt of all the equipment, except the line conductors. This will be true of the operating expenses also. Therefore, since the interest charges and the charges for depreciation and repair are dependent upon the investment, the greater the output of the plant the less will be the quantities going to make up the annual cost per kilowatt of transmitting power, except those depending upon the line conductors. Since the weight of the line conductors under the conditions assumed will vary directly as the amount of power transmitted, those elements of the annual cost per kilowatt depending upon the line conductors

will be practically constant for all amounts of power transmitted and cannot be materially reduced by increasing the amount of power transmitted. With the same voltage, economic drop, and output, the elements of annual cost per kilowatt due to the line structure (pole line) and to its extent (patrolling, etc.), will increase directly at the distance. But, as outlined above, any increase of cost in line structure due to increase in distance can be offset by increase of output. On the other hand, the weight of the line conductors increases as the distance (for the same *economic* drop) and the elements of annual cost per kilowatt due to the weight of the line conductors will, therefore, increase as the distance, no matter what the output.

It appears, therefore, that all the elements in the annual cost per kilowatt for transmitting power, except those dependent upon the line conductors, may be continually reduced by increasing the amount of power to be transmitted. The annual cost per kilowatt due to the line conductors cannot be so reduced. It can be diminished only by such other means as will reduce the first cost of the conductors. As the first cost of the line conductors can be reduced only by increasing the voltage of transmission and as there is a limit to which such increase can be carried, it follows that *the limiting distance to which power can be economically transmitted will depend, finally, upon the cost of the line conductors and upon this alone.*

The limit of voltage referred to is not necessarily that due to physical considerations, such as difficulties of construction, air losses between conductors, etc.; for, leaving such matters out of consideration, it is easy to imagine the voltage carried to such a high value as will reduce the line conductors to the point when the increased cost of transformers and insulators, due to a further increase of voltage, will overbalance the saving in the line conductors, due to such further increase.

It will somewhat simplify the treatment of the subject if the interest charge be included as a part of the cost of transmission, and profits be represented by a percentage on the investment. This course will, therefore, be pursued. That is, it will be assumed that in the cost of transmission is included the interest on the investment (bond interest) and that over and above this cost there must be earned a certain percentage, which percentage will represent profits (stock dividends). In addition the following assumptions will be made:

Power purchased at low-tension bus-bars of step-up transformers and sold at outgoing bus-bars of the step-down station.

Frequency of transmission not less than 25 cycles nor more than 30 cycles as being the limiting frequencies which, while favorable to the transmission of power, are yet suitable for almost all purposes to which power can be applied.

Idle synchronous motors at step-down station to correct for power-factor, the average power-factor of the line being held as near unity as possible. In the plants of large output dealt with below, the possible approximation to unity power-factor will, in spite of the line-charging current, be sufficiently close, for practical purposes, to justify the assumption of unity power-factor.

That no matter what the capacity of the plant, there will be three transmission lines, each capable of carrying one third the load.

That the power-factor of the load supplied will be 0.8.

That no matter what the size of the plant the number of transforming units at each end of the line be 18, each transformer being normally worked at $\frac{4}{5}$ of its rated capacity, so that one bank of three may be cut out, if need be.

That no matter what the size of the plant the number of corrective synchronous motors will be six, each being worked at $\frac{4}{5}$ of its rated capacity. The kilovolt-ampere capacity of these synchronous motors must, for a load power-factor of 0.8, be equal to $\frac{3}{4}$ of the kilowatt capacity of the load carried by the plant.

It is evident that the number of units must be considered as the same for plants of all capacities in order to take full advantage of the decrease of cost per kilowatt, due to increase of capacity.

The pole lines will be assumed as constructed with 12 steel towers to the mile.

Ideal conditions will be assumed throughout consistent with delivering reliable and cheap power. Since the object is to determine the *maximum* distance, the factors fixing commercial costs of apparatus will be taken at the lowest values likely to obtain.

Later on in this paper general equations are derived expressing the relations between the distance of transmission and the quantities which govern it. By making assumptions, in addition to those mentioned above, as to the values of the

various coefficients in the general equations and as to the purchase price and selling price of power, the curves of Figs. 1, 2, 3, 4, and 5 have been obtained which are given and discussed here instead of at the end of the paper.

Fig. 1 shows the relation between the distances of tranmission, D, and the economical voltage, E, for different kilowatt outputs, W; that is, it shows the voltage which it is most economical to use

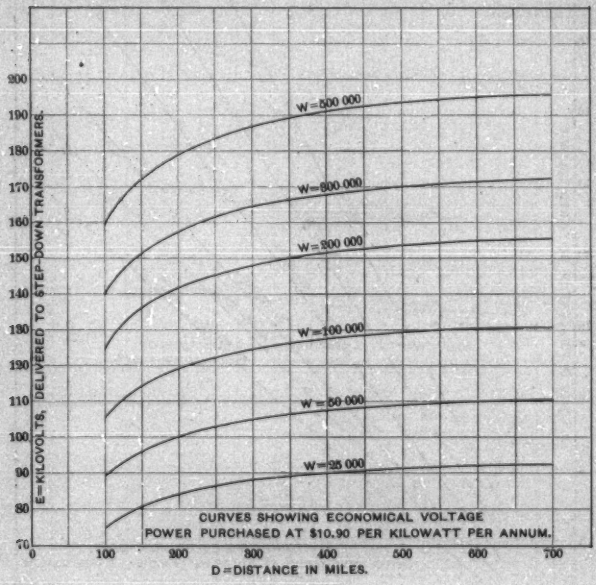

FIG. 1.

for any given output and distance of transmission.

Fig. 2 shows, in a corresponding manner, the economical drop.

Fig. 3 shows the diameter of the conductors corresponding to the conditions of Figs. 1 and 2.

Fig. 4 shows the relation between D, the distance of transmission, and p, a percentage net profit on the investment for

different values of output W and for selling price of \$34 per kilowatt per annum.

Fig. 5 is a curve obtained from Fig. 4 and shows the relation between the distance of transmission and the output for a net profit of 12%.

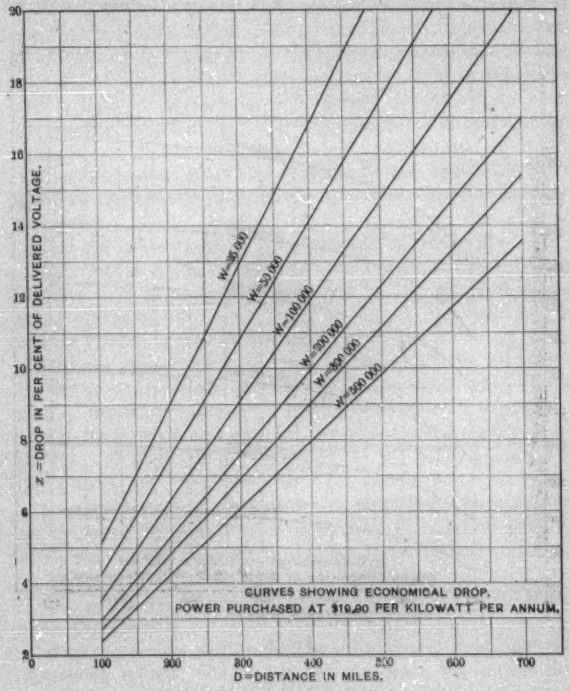

FIG. 2.

In obtaining these curves the constants have all been given values favorable to long transmission distances. The costs have been taken lower than those ordinarily current in the endeavor to anticipate somewhat possible future prices. Also, the cost of power purchased at the step-up station has been fixed

at the very low figure of $10.90 per kilowatt per annum. These facts should be carefully borne in mind in considering the curves, which will all be more or less modified by changes in the quantities mentioned.

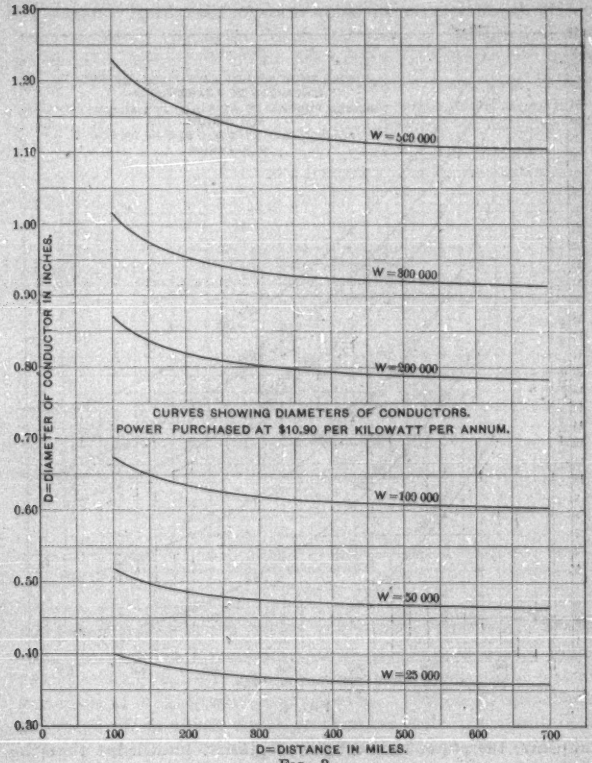

FIG. 3.

On comparing the diameters of conductors given by Fig. 3 and the voltages to which they correspond with the values of diameter and critical voltage given by Professor Harris J. Ryan

in his splendid paper on that subject,* it appears that the diameters of Fig. 3 are considerably above those of the paper mentioned. The values of Fig. 3 are affected by the price paid for power at the step-up transformers, but if this be taken even as high as $20 per kilowatt per annum instead of $10.90, the diameters of the conductors remain below those for the critical voltages. It

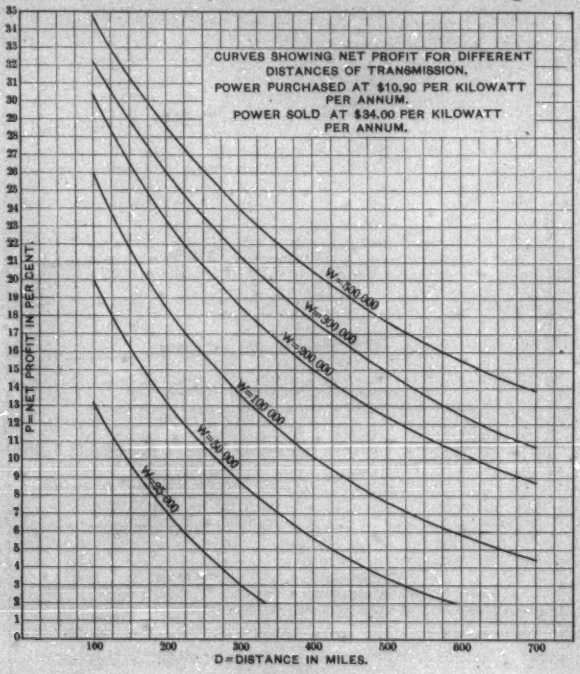

FIG. 4.

appears, therefore, in the light of present knowledge that the limit of voltage will come through economic conditions and not through conditions depending upon atmospheric losses.

It is difficult to fix upon a figure for the selling price of the

*See paper read by Professor Ryan before AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, February 26, 1904.

delivered power which shall be representative. Power prices are so dependent upon conditions, especially those arising from the location and magnitude of the market and of the supply, that any figure chosen will be objected to by some as too high and by others as too low. The same condition applies to the price assumed as that paid for power at the step-up station but in a lesser degree. The figure herein assumed as the price of the power sold, $34 per kilowatt per annum, is that which seems to the writer will be fairly representative, especially in the case of the large blocks of power. The writer does not, however, wish to be understood as committed to an opinion by

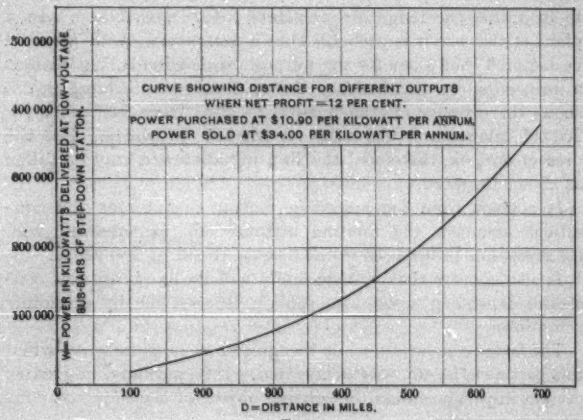

FIG. 5.

the power prices herein, either in the case of purchase or of sale. The values taken have been chosen as being as nearly representative as possible of the best conditions which might obtain, favorable to long distance transmission. If these figures should be criticised in about equal proportions from the standpoints of being too low and too high, respectively, the object in choosing them will have been accomplished, since such criticism will be evidence of their fairness as a reasonable compromise.

The voltages to which the curves apply are much higher than those now in use commercially, but they are not beyond the range of future possibility. Manufacturers will now under-

take commercial transformers for voltages as high as 150 000 volts, and there is little question that when the demand shall come for units of the large capacities contemplated herein, the voltage requirements will be met. Such transformers will be structures of sufficient size to permit of being gotten at and worked upon from the inside as well as the outside and this, in connection with the fact that more space may be utilized for insulation, will render construction for high voltages much less difficult than at present.

The maximum amount of power dealt with herein, 500 000 kilowatts, is probably too high to be seriously considered at this time, but from 200 000 to 300 000 kilowatts is believed to be within the range of immediate future possibility. In a plant of this size it is probable that a net return of 12% would be required, not alone for the purpose of dividends, but also as a protection to the bonds. Under these conditions Fig. 5 shows the distance of transmission to vary from 512 miles for 200 000 kilowatts to 623 miles for 300 000 kilowatts. For the present outlook, therefore, the limiting distance may be taken as about 550 miles.

It appears from the preceding matter that under the conditions assumed, the limiting distance of transmission will, for some time at least, be in the neighborhood of 550 miles.

It also appears that voltage limits will be fixed not by conditions depending upon atmospheric losses, but by economic conditions.

The latter conclusion, while recognized as a possibility when this paper was begun, was unexpected. It is, perhaps, of greater present importance than the original object of the paper as conveyed in the title.

* * * * * * * * * *

The analysis on which depends the general equations from which the preceding curves were obtained will now be taken up.

Let E = voltage, in kilovolts, delivered to step down transformers.

D = distance of transmission in miles.

x = percentage of power lost in the line in terms of delivered power.

e = efficiency of the whole system.

e_1 = combined efficiency of step-up and step-down transformers and synchronous motors.

d = diameter of line conductors in inches.

W = power, in kilowatts, delivered at low voltage bus-bars of step-down station.

c = cost, in dollars per kilowatt per annum of power purchased at the low-voltage bus-bars of the step-up transformers.

Let s = price, in dollars, received for power per kilowatt per annum at the low-voltage bus-bars of the step-down station.

h = a quantity which, multiplied by c, will give the cost at the high-voltage terminals of step-up transformers.

R = total interest maintenance and depreciation charge per annum.

L = cost of labor for operating transformer stations and for executive and clerical services.

M = total investment.

C = total cost per annum of power delivered, inclusive of interest.

p = a percentage covering profit.

$\therefore \quad e = \frac{e_1}{1+x}$, since $\frac{1}{1+x}$ is the efficiency of the line.

$\therefore \quad \frac{W c}{e} = \frac{W c\,(1+x)}{e_1}$ = total amount expended per annum for power purchased.

$\therefore \quad W s$ = total amount received per annum for power.

$$\therefore \quad C = \frac{W c}{e} + L + R$$

$$\therefore p = \frac{W s - C}{M} = \frac{W s - \frac{W c}{e} - L - R}{M} = \frac{W s - \frac{W c\,(1+x)}{e_1} - L - R}{M} = \frac{N}{M} \qquad (1)$$

Now M is made up of

(1) Cost of transformers.
(2) Cost of transformer switchboard apparatus, cables, lightning protection, etc.
(3) Cost of building and real estate.
(4) Cost of insulators.
(5) Cost of pole-line material and construction.
(6) Cost of right of way.
(7) Cost of corrective synchronous motors and exciters.

(8) Cost of switchboard apparatus, cables, etc., for synchronous motors.

(9) Cost of line conductors.

Cost of transformers will depend upon voltage and output;

$f_1(E,W)$

Cost of transformer cables and controlling apparatus will depend upon same quantities as transformers, but in a different way;

$f_2(E,W)$

Cost of building will depend upon output;

$f_3(W)$

Cost of insulators will depend upon voltage, diameter of conductors and number required; *i.e.*, voltage, diameter of conductor, and distance of transmission;

$f_4(E, d, D)$

Cost of pole line construction will depend upon diameter of the conductors and the distance. But the diameter of the conductors depends upon voltage, drop, output, and distance; hence,

$f_5(d, D) = f_5(E, W, x, D)$

Cost of right of way will depend upon distance only;

$f_6(D)$

Cost of synchronous motors will depend upon output only, since all other elements affecting cost will be fixed;

$f_7(W)$

Cost of switchboards and cables for synchronous motors will depend upon output only;

$f_8(W)$

Cost of line conductors will depend upon voltage, output, line loss allowed, and distance of transmission;

$f_9(E, W, x, D)$

The sum of these nine functions constitutes M, the total investment.

Now R, the total interest and depreciation charge, depends upon all of the several quantities making up M.

In what follows the numerical value of the constants are those taken for the specific problem treated herein.

Let $p_1 = 0.125$, being the percentage of transformer cost for interest, depreciation, and repairs.

$p_2 = 0.125$, being the percentage of transformer switchboards cost for interest, depreciation, and repairs.

$p_3 = 0.075$, being the percentage of buildings, cost for interest, depreciation, and repairs.

$p_4 = 0.10$, being the percentage of insulator cost for interest, depreciation, and repairs.

$p_5 = 0.125$, being the percentage of pole line cost for interest, depreciation, and repairs.

$p_6 = 0.05$, being the percentage of cost of right of way, for interest only.

$p_7 = 0.125$, being the percentage of synchronous motor cost of interest, depreciation, and repairs.

$p_8 = 0.125$, being the percentage of cost of synchronous motor, switch-board, etc., for interest, depreciation, and repairs.

$p_9 = 0.05$, being the percentage of cost of conductors, for interest.

R = the sum of these percentages multiplied respectively into the several quantities to which they refer

L depends only upon output

$$f_{10}(W)$$

The numerical values given for the percentages p_1, p_2, etc., are those which will be used in the specific problem herein treated. The rate of interest has in all cases been taken as 0.05, so that by subtracting this from the above values the depreciation assumed in each case may be determined.

If there be substituted in equation (1) the values of M, L, and R, as expressed by the above symbols, there will result an equation expressing in the most general terms the relations between the distance of transmission and the quantities which govern it. This substitution results in rather an unwieldy expression and will be omitted.

Before proceeding with the determination of the forms of the several functions indicated it will be necessary to enter into a discussion of the relations existing between voltage and line loss, and the quantities governing them respectively.

Let q = that portion of the cost per kilowatt at the low-tension bus-bars of the step-down station, which is due to line loss and to interest on the value of the conductors; then, anticipating in part the matter of a few pages further on

$$q = \frac{p_9 K_9 \frac{W D^2}{E^2 x} - hc\, Wx}{W}$$

in which $p_9 K_9 \frac{W D^2}{E^2 x}$ is the interest on the conductors and $hc\, Wx$ the cost of the power lost in the line.

Setting the first derivative of this with respect to x equal to zero, in order to determine the value of x corresponding to the minimum value of q, we find the well known expression for economic drop

$$x = \left(\frac{p_0 K_0}{hc}\right)^{\frac{1}{2}} \frac{D}{E} = n\frac{D}{E} = .038\frac{D}{E} \qquad (2)$$

From this equation for x we may obtain the equation

$$p_0 K_0 \frac{D^2}{E^2 x} = hcx$$

But the first member of this equation is the interest on the line conductors per kilowatt delivered, and the second member is the annual cost of the line loss per kilowatt delivered. That is, for most economical conditions the line loss per kilowatt delivered must be equal in value to the interest on the conductors per kilowatt delivered—a relation already well known.

As has already been suggested, there will be a limit to which the voltage can be carried, due to the fact that, although increase of voltage will diminish the annual cost of lost power and of conductors, it will increase the annual cost of certain other important factors. The elements of annual cost which are affected by change of voltage are the interest and depreciation of the transformers, the interest on the line conductors, the line loss, and the interest and depreciation of the insulators. The first and last items will increase with the voltage, because of the increased first cost, due to the increase of voltage; the other two will diminish.

Let q_1 = that portion of the annual cost per kilowatt of delivered power due to the line loss, conductors, insulators, and transformers. It has just been shown that for best economy the line loss and annual conductor cost must be equal, so that twice the line loss, $2hcWx$, may be taken as representing the sum of the annual cost due to line loss and to the conductors. As will be shown later, the cost of the insulators will vary as the distance of transmission, and as the cube of the voltage and the cost of the transformers may be represented by

$$K_1'(E+K_1'')W^{\frac{1}{3}}$$

Hence remembering that p_1 and p_4 are the interest and depreciation of transformers and insulators, respectively,

$$q_1 = \frac{2\,hc\,W\,x + p_4 K_4 E^3 (1+x)^3 D + p_1 K_1' (E + K_1'') W^{\frac{1}{2}}}{W}$$

or, putting in the value of $x = \left(\frac{p_0 K_0}{hc}\right)^{\frac{1}{2}} \frac{D}{E} = n \frac{D}{E}$.

$$q_1 = \frac{2\,h\,n\,WDE^{-1} + p_4 K_4 E^3 (1 + n\,D\,E^{-1})^3 D + p_1 K_1' (E + K_1'') W^{\frac{1}{2}}}{W}$$

Now if the first derivative of q_1 with respect to E be set equal to zero to determine the best value of E, there results a quartic equation more interesting than valuable, so far as the present purpose is concerned. It will greatly simplify matters if instead of substituting the value of x in $(1+x)^3$ we substitute for x, x_1, a fixed drop of such value as will correspond to the average cost of insulator between the two extreme values of x which will be met with in practice; as will be shown later, the error due to such a course will be small. Hence

$$q_1 = \frac{2\,hcn\,W\,D\,E^{-1} + p_4 K_4 E^3 (1+x_1)^3 D + p_1 K_1' (E + K_1'') W^{\frac{1}{2}}}{W}$$

Setting the first derivative of this equation equal to zero, s lving and substituting the value $n = \left(\frac{p_0 K_0}{hc}\right)^{\frac{1}{2}}$ there results

$$E = \left(\frac{-p_1 K_1' W^{\frac{1}{2}}}{6 p_4 K_4 (1+x_1)^3 D} + \sqrt{\frac{p_1^2 K_1'^2 W}{36 p_4^2 K_4^2 (1+x_1)^6 D^2} + \frac{2\,(hc\,p_0 K_0)^{\frac{1}{2}} W}{3 p_4 K_4 (1+x_1)^3}}\right)^{\frac{1}{2}}$$

$$= \left(-3066\frac{W^{\frac{1}{2}}}{D} + \sqrt{9400356\,\frac{W}{D^2} + 3438.5\,W}\right)^{\frac{1}{2}} \qquad (3.)$$

This shows that the voltage may be increased with increase of output, which was to be expected since those costs which limit the voltage will diminish in their amount per kilowatt as the output increases. The value of x_1 used in the above equation was determined upon as follows: The minimum percentage drop which is ever likely to obtain is, say, 2.2, the maximum is, say, 11.5. The reason for selecting these values will be apparent on considering the values of E calculated from the above equation, and given below, in connection with the values of W to which they corre-

spond, and the respective distances to which in each case the various amounts of power would probably be transmitted. The intermediate value of drop which will give the average insulator cost is 6.45%, and this value of x_1 is taken. With this value of x_1 the maximum error in insulator cost, between the limits assigned, will have place when $x = 2.2$ and $x = 11.5$. The percentage error at either of these limits is about 13%. But, as appears in the solution of the first derivative, at the point of minimum of the variables affected by the voltage the combined values of the annual cost due to the conductors, the annual cost of the line loss, and that portion of the annual transformer cost due to voltage, is more than three times that due to the insulators. The total variable quantity involved, therefore, is more than four times the annual cost due to insulators, and the error as a percentage of the total of values of the variables involved is less than $\frac{13}{4} = 3.25$, instead of 13%. As will be seen on examining the manner in which x_1 enters the equation for E, the maximum error in E will be less than 3%, also which will to a like extent affect the values of x. This error is negligible so far as the main problem is concerned, and indeed as far as the question of voltage itself is concerned.

In Fig. 1 are shown curves plotted from equation (3). These curves show the kilovolts E for different distances D, and different outputs W. Fig. 2 gives curves plotted from equation (2), using the values obtained from the curves of Fig. 1. The curves of Fig. 2 show the percentage drop x for different distances D, and different outputs W. In Fig. 3 are curves showing the diameters of the conductors for the conditions of Figs. 1 and 2. These diameters were calculated from the formula

$$d = k'_s \left(\frac{WD}{E^2 x}\right)^{\frac{1}{2}} = k'_s \left(\frac{WD}{E^2} \frac{E}{nD}\right)^{\frac{1}{2}} = \frac{k'_s}{n^{\frac{1}{2}}} \left(\frac{W}{E}\right)^{\frac{1}{2}} = 0.0219 \left(\frac{W}{E}\right)^{\frac{1}{2}} \quad (4)$$

which gives the diameter d, in inches, of a *solid* conductor. These diameters were in this case calculated for a solid conductor instead of a stranded one because we have at present available data as to the critical point in the atmospheric loss curve for solid conductors only, and while perhaps this critical point will come at a higher voltage in the case of the stranded conductor with its greater diameter, there are no definite data at present on the subject. On comparing the diameters of con-

ductors given by Fig. 3 and the voltages to which they correspond with the values of diameter and critical voltage given by Professor Ryan* we see that the diameters of Fig. 3 are considerably above those of Prof. Ryan's paper. It appears, therefore, from the present knowledge available, that the limit of voltage will come through economic conditions, and not through limitations connected with atmospheric losses.

In the determination of both x and E the quantity h has been employed. This quantity is a factor which, when multiplied into the cost of power at the low-tension bus-bars of the step-up transformers, will give the cost of power at the high-tension terminals of the transformers. That is to say, h takes account of all charges which should be made against this power, including interest and depreciation of the step-up station, transformers, etc., and labor for operating the station, also the loss in the transformers. Now, strictly, there should be substituted for h, the proper functions of the quantities on which it depends, but to do so would seriously complicate the equations and would be of little utility, since h can be approximated with sufficient accuracy in any particular case, and the manner in which it occurs in both x and E is such as to make the error in the quantities due to an error in h much smaller than the error in h itself. In the specific problem herein the value $c = 10.9$ is taken as being the lowest which will probably ever obtain, where large amounts of power are available within transmission distance of a desirable market. The value taken for h in the determination of E and x is $h = 1.1$, so that $hc = 12$.

The next step is the determination of the forms of the several functions indicated. In what follows the constants have been evaluated for the specific problem herein. The costs resulting from the use of these constants will be found to be, in general, considerably less than present commercial costs. The constants were purposely based on prices less than can be now obtained, in the endeavor to anticipate, somewhat, possible future prices.

From a careful consideration of transformer prices, it has been determined that, for transformers of 1500 kw. and over, the cost installed very closely follows the law,

$$f_1(E, W) = K_1'(E + K_1'')W^{\frac{1}{2}} = 13.(E + K_1'')W^{\frac{1}{2}},$$

$$\therefore p_1 f_1(E, W) = p_1 K_1'(E + K_1'')W^{\frac{1}{2}} = 1.625(E + K_1'')W^{\frac{1}{2}}$$

*See foot note, page 878.

in which K_1' is a constant and K_1'' a "variable constant," a quantity which varies slowly with the output in accordance with the law,

$$K_1'' = k_1 + k_1'' W = 55 + 0.000227\, W$$

Theoretically the transformer cost would vary with the drop x_1, since the step-up transformers would have an output and voltage greater than the step-down transformers. Practically, however, step-up and step-down transformers are built so nearly in the same lines that the drop would make little difference. Such difference as would exist can be taken care of approximately by adjustment of the constants, which has been done.

While the apparatus for the control of the high-tension side of the transformers would theoretically vary with the voltage, such variation for 50 000 volts and over will be small, since in most modern plants the high-tension switching apparatus is simple; and higher voltages are likely to cause it to remain so. The lightning protection for the high-voltage lines might vary with the voltage, but it is probable that for high voltages there will soon be a reversion to much simpler and inexpensive apparatus than we use now, so that the variation, if any, due to higher voltages, will be negligible. The switch board for the lower voltage side of the transformers will vary only with the output, since we assume the lower voltage to be the same in all cases, say 6000 volts or thereabouts. The apparatus for the control of transformers may, therefore, be considered as depending only upon output. Under this assumption a consideration of costs of transformers, controlling apparatus and cables, shows that we may assume, with a close degree of accuracy, that

$$f_2(E, W) = K_2' + K_2'' W = 21\,000 + 0.9\, W$$

$$\therefore p_2 f_2(E, W) = p_2 K_2' + p_2 K_2'' W = 2625 + 0.1125\, W$$

The cost of buildings and the real estate for them will increase very slowly with the output. The variation of this item due to variation of output can be expressed closely enough by

$$f_3(W) = K_3' + K_3'' W^{\frac{1}{2}} = 125\,000 + 125\, W^{\frac{1}{2}}$$

$$\therefore p_3 f_3(W) = p_3 K_3' + p_3 K_3'' W^{\frac{1}{2}} = 9375 + 9.375\, W^{\frac{1}{2}}$$

The cost of an insulator will, theoretically, vary with the diameter of the conductor and the voltage. Practically, how-

ever, the diameter of the conductor will have nothing to do with the cost. A consideration of insulator prices shows that the cost of an insulator will vary as the sum of a small constant plus the product of a constant into the cube of the voltage. With high voltages the small constant is negligible, so that we may write

$$f_4(E, d, D) = K_4 E_3 (1+x_1)^3 D = 0.000732 (1.0645)^3 E^3 D = 0.000883 E^3 D.$$

$$\therefore p_4 f_4(E\,d\,D) = p_4 K_4 E^3 (1+x_1)^3 D = 0.0000883 E^3 D$$

The cost of the pole-line material and construction will depend somewhat upon the diameter of the conductors, since, as the diameter of the conductors increases, the wind and sleet stresses will increase. The increase of cost with increase in diameter of conductors will be slow. The law followed will be that of a constant plus a function of the diameter of conductors, since, no matter how small the diameter of conductor, there will be a certain cost representing the minimum sized pole which would be employed. We may, with a fair degree of accuracy, write

$$f_5'(d, D) = (K_5' + K_5'' d) D = f_5(E, W, X, D) = K_5' D + K_5'' k_5 \left(\frac{W}{E^2 x}\right)^{\frac{1}{2}} D$$

or, putting in the value of $x = n\frac{D}{E}$,

$$f_5(E, W, x, D) = K_5' D + \frac{K_5'' k_5}{n^{\frac{1}{2}}} \left(\frac{W}{E}\right)^{\frac{1}{2}} D = 3000 D + 37.2 \left(\frac{W}{E}\right)^{\frac{1}{2}} D$$

$$\therefore p_5 f_5(E, W, x, D) = p_5 k_5' D + p_5 \frac{k_5'' x_5}{n^{\frac{1}{2}}} \left(\frac{W}{E}\right)^{\frac{1}{2}} D = 375 D + 4.65 \left(\frac{W}{E}\right)^{\frac{1}{2}} D$$

which answers for a stranded conductor.

Cost of right of way will be directly proportional to distance, hence

$$f_6(D) = K_6 D = 1000 D$$

$$\therefore p_6 f_6(D) = p_6 K_6 D = 50 D$$

A consideration of synchronous motor prices shows that the cost of synchronous motors may be written,

$$f_7(W) = K_7' + K_7'' W = 12\,000 + 32.4\,W$$

$$\therefore p_7 f_7(W) = p_7 K_7' + p_7 K_7'' W = 1500 + 4.05\,W$$

From the well known relations between the cost of conductors, and the voltage distance, output, and drop, we may write

$$f_9(E, W, X, D) = K_9 \frac{W D^2}{E^2 x} = 0.346 \frac{W D^2}{E^2 x}$$

or, putting in the value of $x = n \frac{D}{E}$

$$f_9(E, W, X, D) = K_9 \frac{W D}{E n} = \frac{K_9}{n} \frac{W D}{E} = 9.1 \frac{W D}{E}$$

$$\therefore p_9 f_9(E, W, X, D) = p_9 K_9 \frac{W D}{E n} = 0.455 \frac{W D}{E}$$

The cost of labor, for the operation of the step-up and step-down transformer stations, and for executive and clerical purposes, would probably not vary at all. We have, in each case, the same number of units to be looked after, and the size of these units would make little, if any, difference in the cost of attendance upon them. Similarly, the output will make little difference in executive and clerical costs. We would probably be justified in making $f_{10}(W)$ a constant. In order, however, to cover such small increase in labor and salaries as there might be with increase of output we will write

$$f_{10}(W) = K_{10}' + K_{10}'' W^{\frac{1}{2}} = 32\,000 + 26\,W^{\frac{1}{2}}$$

It is to be noted that the labor in connection with the line is taken care of in the depreciation and repair percentages applicable to the supporting structure and insulators respectively.

The efficiency of the whole system is $\frac{e_1}{1+x}$

Putting in the value of $x = n \frac{D}{E}$

$$e = \frac{e_1}{1 + n \frac{D}{E}} = \frac{0.925}{1 + 0.038 \frac{D}{E}}$$

$$\frac{W c}{e} = \frac{W \left(1 + n \frac{D}{E}\right) c}{e_1} = \frac{W c}{e_1} + \frac{n c}{e_1} \frac{W D}{E} = 11.78\,W + 0.448 \frac{W D}{E}$$

The various functions above arrived at may now be utilized in obtaining N and M of equation (1), $p = \frac{N}{M}$.

Remembering that R is the sum of the products of the various functions by the corresponding percentages representing interest, depreciation, and repair; that $L = f_{10}(W)$, and representing the various resulting collections of constants as follows

$$\begin{aligned} a &= p_2 K_2'' + p_7 K_7'' + p_8 K_8'' && = 4.184 \\ b &= K_{10}' + p_2 K_2' + p_3 K_3' + p_7 K_7' + p_8 K_8' && = 46\,550 \\ m &= K_{10}'' + p_2 K_2'' && = 35.38 \\ r &= p_5 K_5' + p_6 K_6 && = 425 \end{aligned}$$

then $N = W s - \frac{W c (1+x)}{e_1} - L - R$

$$(s - \frac{c}{e_1} - a)\ W - \left(\frac{n c}{e_1} + \frac{p_5 K_5}{n}\right) \frac{W D}{E} - m W^{\frac{1}{2}} - p_1 K_1' (E + K_1'') W^{\frac{1}{2}}$$

$$- p_4 K_4 (1+x_1)^3 E^3 D - r D - \frac{p_5 K_5'' k_5}{n^{\frac{1}{2}}} \frac{W^{\frac{1}{2}}}{E} D - b.$$

Representing constants as follows

$$\begin{aligned} \alpha &= K_2'' + K_7'' + K_8'' && = 33.47 \\ \beta &= K_2' + K_3' + K_7' + K_8' && = 166\,400 \\ \gamma &= K_5' + K_6 && = 4000 \end{aligned}$$

$$M = \alpha W + \frac{K_5}{n} \frac{W D}{E} + K_3'' W^{\frac{1}{2}} + K_1' (E + K_1'') W^{\frac{1}{2}}$$

$$+ K_4 (1+x_1)^3 E^3 D + \gamma D + \frac{K_5'' k_5}{n^{\frac{1}{2}}} \frac{W^{\frac{1}{2}}}{E} D + \beta.$$

These values of N and M, if substituted in equation (1) will give, in its final form, the equation connecting distance, output, voltage, and profit, or, in connection with equation (3), for voltage, the relation between distance, output, and profit. Such substitution results in a cumbersome equation and will not be made here. If the various numerical values, already determined for the specific problem herein treated, be substituted in N and M, there results,

$$N = (s - 15.96)\ W - 0.903 \frac{W D}{E} - 35.38\ W^{\frac{1}{2}} - 1.625\ (E + K_1'') W^{\frac{1}{2}}$$

$$-0.0000883\,E^3\,D-425\,D-4.65\left(\frac{W}{E}\right)^{\frac{1}{2}}D-46\,550$$

$$M=33.47\,W+9.1\frac{W\,D}{E}+125\,W^{\frac{1}{2}}+13(E+K_1'')W^{\frac{1}{2}}+0.000883\,E^3D$$

$$+4000\,D+37.2\left(\frac{W}{E}\right)^{\frac{1}{2}}D+166\,400.$$

The value of s in the above equation for N is taken as 34, that is, it is assumed, for the purposes of the specific problem, that power is sold at $34.00 per kilowatt. Putting in this value of s and calculating the value of p for different outputs, W, and different distances, D, the curves of Fig. 4 have been obtained. These curves show, for different values of W, the relation between p and D. Assuming that the minimum acceptable profit is 12 per cent, and taking from Fig. 4 the values of D and W corresponding to this percentage profit, there has been plotted the final curve, Fig. 5, which shows the relation between distance and output.

In considering these curves, the assumption made in connection with them should be carefully borne in mind. A small change in the purchase price or selling price of power will make a great difference in the result. Smaller amounts of power will in general be purchased at a higher price per kilowatt, but on the other hand they would probably be transmitted to points where the power would bring a higher price, since in general, the larger the market the cheaper can power be produced by steam.

It would be interesting to let $s-c/e_1$ equal to zero and determine p which would then be the cost, including interest, of operating the plant. If curves showing the percentage of the investment for operation were thus determined, also the total cost of the plant, both for various outputs, the results would be valuable in preliminary estimates. The writer hopes to work up such data, later.

It will be noticed on referring to the curves that some of them reached to distances which caused the drop to exceed the value taken for the upper limit of drop in connection with insulator cost. The error due to 1 or 2% excess will not greatly affect the final result. It would have been somewhat better however, for the specific problem treated, to have chosen the limits of drop as 5% and 10% respectively instead of those taken.

DISCUSSION ON "THE TELAUTOGRAPH."

F. C. BATES: Possibly Mr. Dixon will give us a practical demonstration of the working of the telautograph.

(Mr. Dixon gave the demonstration.)

C. O. MAILLOUX: What is the longest distance which has been attained and what are the prospects of longer distances?

JAMES DIXON: The distance is apparently purely a matter of resistance. The highest worked through so far is 1600 ohms in each writing line. The longest line at present in actual operation is seven miles in length, submarine cable, in the service of the U. S. Signal Corps.

The army instruments are of special construction, to permit working out of doors without protection from the weather, hence they are mounted in weather-proof brass cases. The messages must be visible at night and a lamp is therefore placed in the case. This lamp lights when the instrument is in operation.

E. B. FAHNESTOCK: How does a variation in the insulation of a line affect the work?

JAMES DIXON: It affects the shape of the fields to some extent. If it is uniform in both lines it can be compensated for by a line resistance adjuster at the transmitter. In all army work a receiver is mounted before the eyes of the sender and he can see the form in which the message is going to line. If he finds that the field is out of shape he can adjust the line resistance and correct it. In commercial work this difficulty has not yet been met as all the lines in service are of high insulation.

F. C. BATES: Will Mr. Dixon tell us if it is possible to send a message to several different stations at the same time?

JAMES DIXON: The two army series receivers exhibited are part of a set of seven, all of which operate in series and record the same message. Seven receivers can be operated at once by a standard transmitter containing only one pair of rheostats. To operate more than seven receivers one or more pairs of rheostats and rollers are added, making a double or triple transmitter, in which all the rollers are moved by one pencil. Each pair of rheostats operates seven receivers; that is, a triple transmitter can write to three branches of seven receivers or 21 receivers in all. Multiple operation is possible within certain limits, by using high resistance in the suspended coils and connecting the instruments to the line in multiple. The resistance of copper wire that can be wound on the coils without exceeding a reasonable weight is limited and places a limit on multiple operation.

A. C. CREHORE: Is it an error in the paper stating that one ampere is required?

JAMES DIXON: That value is correct. In the transmitter the rheostats each carry about one-quarter of an ampere, the induction coil primary circuit about one-eighth, and each of

the line currents may be as much as two-tenths, making about one ampere which is supplied to the transmitter from the power circuit. In the receiver the field-magnet winding, excited from the power circuit, takes about six-tenths of an ampere, the paper-shifter about one-fourth, and the pen-lifter one-tenth, making a total of about one ampere supplied to the receiver. The line currents are of course variable and range between a maximum of three-tenths and a minimum of nearly zero.

TOWNSEND WOLCOTT: These army instruments were designed especially for the Signal Corps and, as Mr. Dixon has said, one of the principal requirements was that they should be able to withstand the concussion of the guns. There was, at first, some doubt whether the instruments could endure the strain; but so far they have come through unscathed. To be sure, there has been no real warfare in which the telautographs were used, but in the maneuvers at Portland, Maine, a year ago last summer, telautographs were successfully used in a mortar pit, where the suction from the simultaneous discharge of all the mortars was so great that one day it pulled the clapboards off the front of an adjacent building. All this did not prevent the telautographs from working. The ink used to be spattered, in the old type of instruments, but this has been overcome in the present type. The use of the telautograph in the army is to convey information from the range-finder to the guns.

JAMES DIXON: In reference to the effect of shock or concussion from the guns, these particular instruments, (the instruments used in the demonstration), were installed and in use on the battleship Alabama for some time and were subjected to severe tests. One was placed near the trunnions of a 13-inch gun, and about four feet from the gun axis, the gun being trained parallel to the instrument. Repeated shots with full service charges did not develop any faults in the construction or operation of the instrument. These receivers are in the condition in which the test left them, and their operation shows them to be uninjured. The army type springs (indicating springs) have been substituted for the navy suspension springs which are slightly different. In army work an anchorage is to be added to the bottom in the form of a third spring, to prevent the receiver from being pushed out of the vertical position, as for instance, by a person leaning against the case. The question of withstanding the shock is of great importance and the instruments as shown meet all the requirements.

DISCUSSION ON "THE TRANSPOSITION OF ELECTRICAL CONDUCTORS."

W. S. FRANKLIN: The speaker's objection to these established methods is that in both cases the fundamental equations are based upon ideal conditions; which even as ideal conditions are impossible and meaningless. Precisely the place where the

mathematics is hitched on to the physics, there is no physics at all, nothing in fact but an unconstrained fiction. Now, the speaker knows of no case in which physically significant mathematics cannot be established on the basis of real conditions. It is physically meaningless to consider a long straight wire as a circuit, and the idea of inductance of such a wire is absurd. It is also physically meaningless, in all strictness, to consider a lone electrical charge; and the capacity of an isolated sphere, so universally discussed in treatises on physics, is very nice and simple, but the student who is drilled in that idea never can quite understand a condenser. The real ideas are inductance of *circuits*, capacities of *condensers*; that is, of two bodies in the simplest cases, and mutual inductance of circuits and coefficients of mutual capacity of condensers. Of course, the speaker does not mean to say that Maxwell's theory of a system of charged bodies is essentially wrong, but he does mean to say that it is not as intelligible, not as thinkable, if you please, as it would be if it did not involve the highly fictitious idea of the electrical pressure coefficient of a body with respect to itself, and of the capacity coefficient of a body with respect to itself. The speaker cannot think of such a thing, and he is sure that a careful analysis of the ideas of anyone who thinks he thinks of the pressure coefficient of a body with respect to itself or of the capacity of a sphere, would reveal the fact that the ideas of that person really refer to mathematical expressions or to words, not to physical things at all.

Mr. Fowle says that cable ends on a long telephone line serve to reduce cross-talk, to increase the effectiveness of the transposition on the middle portions of the line. Does he mean to say that it is because of the attenuation which takes place in the cable ends? or because of the very complete transposition which is accomplished in a twisted cable?

F. F. FOWLE: The decrease in cross-talk, which occurs when there is a terminal cable, is due, in the opinion of the speaker, to the attenuation in the cable, which diminishes the power of the cross-talk currents coming from the distant open-wire line.

W. J. LANSLEY: What does Mr. Fowle regard as the permissible distance, the ordinary minimum distance between telephone circuits and single phase 2000 volt power circuits?

F. F. FOWLE: Does Mr. Lansley mean from the standpoint of the hazard to the circuit or the standpoint of induction?

W. J. LANSLEY: Standpoint of induction.

F. F. FOWLE: It depends not only on the pressure of the circuit, but on the load and on the distance between the wires of the power circuit and the distance between the wires of the telephone circuit. In the opinion of the speaker it is not possible to answer Mr. Lansley's question generally. Perhaps a specific case could be answered approximately.

W. J. LANSLEY: Take the pin distance between the wire. Suppose the 2000 volt wires are eight inches apart, and your

telephone wires are the same distance apart, how far away should the telephone wire be from the power wire, presumably on the same pole line?

F. F. FOWLE: The speaker's opinion, in this case, is that the circuits should be separated at least two or three feet and that the telephone circuit should be transposed every ten poles, or every quarter mile. The size of the wires, the load on the alternating current circuit and the frequency are factors in determining the distance between transpositions. If the two circuits are on the same cross-arm, there is likely to be more leakage than there would be if they were on separate cross-arms. The use of extra heavy insulators on the telephone circuit is advisable.

W. S. FRANKLIN: The speaker understands the difficulty from leakage is partly balanced by transposition. Mr. Fowle do you depend on transposition at all for obviating bad insulation? Do you find it practicable?

F. F. FOWLE: The speaker is not aware that transpositions have been depended on in such cases. In telephone work it is essential to make frequent insulation tests; the insulation should be the same between each wire and earth and should be high. The speaker recalls an insulation measurement on a line nearly 1000 miles long which gave between 40 and 50 megohms per mile, on a dry, clear, cold day. An insulation resistance of 50 megohms per mile in good weather indicates first class construction, with the pony glass in ordinary use. In wet weather the insulation may fall to one megohm per mile, or less; but at one megohm per mile the attenuation is not increased to a noticeable extent and the distortion is diminished.

F. F. FOWLE (*by letter*): Certain of Professor Franklin's remarks do not seem to the writer to be fully justified.

The connection between the physical and the mathematical sides of any question is seldom obvious, in the step by step development, without careful study. This study is obviously the occupation of the student, but the engineer is after results by the shortest paths; and his education and experience enable him to conduct his researches without a too laborious attention to the physical interpretation of each step. The object of the mathematical investigation of inductance and capacity of aerial wires is obvious in Figs. 1 to 4, 8, and 9, and in the application of its results to the choice of types from Fig. 11 in treating a real situation, as exemplified in Fig. 13.

The writer has never seen elsewhere the deduction of equations (40), (41) and (42). The fact that the investigation is an extension of Heaviside's method and is based on Maxwell's fundamental equations, seems an advantage rather than otherwise. If the results are inaccurate or if there are more rational modern methods the writer will gladly learn of it.

[COMMUNICATION.]

BY GEO. H. ROWE.

In an article by the writer on Wave Form Variations,* the prediction was made that the core losses in apparatus operated from the lines of the Standard System would vary 10% under normal conditions of operation due to change in form factor of the electromotive force wave.

To verify this statement the following tests were made, June 17, 1904, on a 300 kw. Stanley transformer. Pressure from the standard line was applied at 2300 volts to the transformer through an induction regulator, by means of which the pressure was maintained constant. The core loss was measured by means of a Weston wattmeter supplied with a non-inductive multiplier. The speed of a synchronous motor running light was used to determine any variation of the frequency. Pressure was applied to the transformer 24 hours before taking observations, water being allowed to flow through the cooling coils until temperature conditions were constant.

The following readings were taken:

Time	Volts	Speed	Temp. fahr.	Kilowatts
9 00	2300	518	94	5.92
9 35	2300	519	94	5.92
10 05	2300	518	94	5.92
10 35	2300	520	94	5.72
11 00	2300	519	94	5.72
11 30	2300	519	94	5.92
11 55	2300	520	95	6.02
12 55	2300	518	96	6.12
1 25	2300	520	96	5.92
1 55	2300	520	96	6.12
2 25	2300	519	97	6.12
3 00	2300	520	97	6.12
3 30	2300	518	98	6.12
4 00	2300	519	98	6.12
4 30	2300	519	98	6.32
4 55	2300	519	98	6.12
5 30	2300	520	98	6.12
6 05	2300	520	98	6.12
6 30	2300	520	98	6.12
7 00	2300	520	98	6.12
7 30	2300	520	98	6.12

*(See page 393, April, 1904, TRANSACTIONS.)

Time	Volts	Speed	Temp. fahr	Kilowatts
8 00	2300	520	98	6.02
8 30	2300	520	98	5.92
9 00	2300	520	99	5.92
9 30	2300	520	102	6.00
10 00	2300	520	100	6.02
10 30	2300	520	100	5.92
11 00	2300	520	99	5.96
11 30	2300	520	100	5.94
1 00	2300	520	98	5.9
2 00	2300	515	96	5.82
3 00	2300	518	94	5.9
4 00	2300	519	94	5.72
5 00	2300	519	93	5.72
6 00	2300	519	92	5.82
6 30	2300	518	92	5.9
7 00	2300	519	94	5.87
7 30	2300	520	94	5.9
8 00	2300	520	94	5.92
8 30	2300	519	93	5.92
9 00	2300	520	93	5.72

The results show a total variation in core loss of 10% of the mean value. If correction is made for the variation of temperature on the assumption of 8% variation in core loss for 40° fahr. variation in temperature, the variation due to variable wave form is increased to 10.8%. The variation in speed is insignificant.

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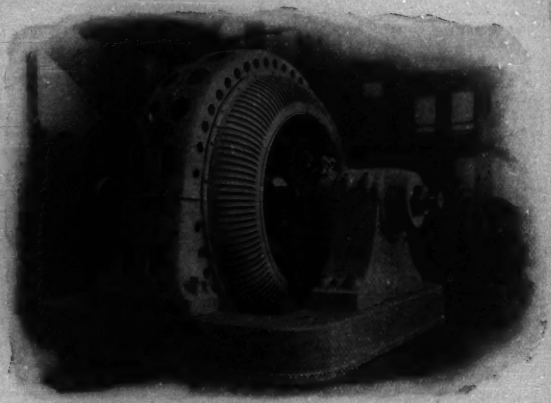

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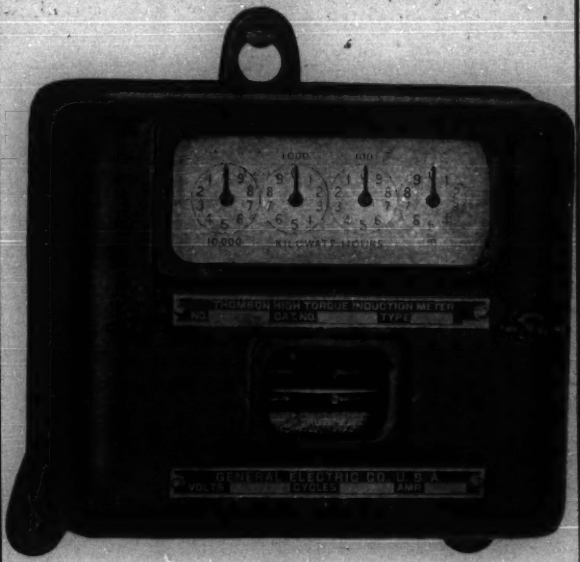

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